

EXHIBIT 32

The logo for Exponent, featuring the word "Exponent" in a white serif font with a registered trademark symbol, set against a teal background. A large, faint, stylized "Ex" is visible in the background of the teal section.

Exponent®

Polymer Science and Materials Chemistry

**Expert Report of
Maureen Reitman, Sc.D.**

**In the matter of the City of
Spokane, WA v. Monsanto, et al.**

Project Number: 1608964.002



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Prepared for

Counsel for Monsanto

Prepared by

A handwritten signature in black ink, appearing to read "Maureen", followed by a long horizontal flourish.

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Scope and Limitations

1.1 Scope of Work Performed

Exponent, Inc. (“Exponent”) was retained by counsel on behalf of defendants Pharmacia Company, Solutia Inc., and Monsanto Company (hereafter referred to collectively as Monsanto) to review documents and testimony, perform analysis, and provide opinions related to polychlorinated biphenyls (PCBs) used as plasticizers, including those in caulk or sealant compounds and other building materials, the formulation effects on the release of PCBs from these materials during their working lifetime, and the condition and composition of these materials found in and around the city of Spokane, WA. My assignment is related to my expertise in polymer materials science, formulation, and product development, as described more fully in the qualifications section.

In this report I present the background of Aroclor PCBs (the PCBs sold by Monsanto as plasticizers) and by-product PCBs (PCBs produced as by-products in various chemical processes), provide a review of the multiple types of technical material Monsanto provided customers regarding the properties of Aroclors, and discuss Aroclor plasticizer use and related customer applications. As part of my scope, I assessed if Aroclor PCBs were a specialty material used for specific and unique applications that were not addressable at the time without the use of PCBs, if developments in the construction industry in the 1950s-1970s and the ability to comply with certain military specifications would have been possible without the use of PCBs, and if there was a one-to-one replacement for PCBs such that products that relied on Aroclor PCBs were unaffected when PCB plasticizers were withdrawn from the supply chain.

1.2 Limitations

This report summarizes work performed to-date and presents the findings resulting from that work. In the course of my analysis, I have reviewed and relied upon documents, testimony, and publicly available literature, as well as my education, training and experience. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the

right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available through ongoing discovery and/or through any additional work or review of additional work performed by others. This report has been prepared in connection with pending or anticipated litigation; any use of Exponent's work product outside this purpose is prohibited.

2 Qualifications and Disclosures

2.1 Qualifications

I hold two academic degrees: (1) a Bachelor of Science in Materials Science and Engineering from the Massachusetts Institute of Technology (MIT), and (2) a Doctor of Science in Materials Science and Engineering, with a thesis in the field of polymers, from MIT. I have been practicing in the field of polymer science and engineering for more than 25 years, as a researcher at MIT, in a variety of technical roles at the 3M Company, and as a consultant with Exponent. I am a licensed Professional Engineer in the state of Maryland and a Fellow of the Society of Plastics Engineers.

I am a Principal Engineer, Corporate Vice President and the Director of the Polymer Science and Materials Chemistry Practice at Exponent, the largest engineering firm in the United States dedicated primarily to the analysis and prevention of failures of an engineering or scientific nature. Exponent is a publicly traded company that employs over 1000 full-time staff worldwide, including about 800 degreed professionals, more than 500 of whom hold doctorates in their field.

I provide consulting engineering services in all aspects of polymer science and engineering including, but not limited to, material selection, product design and development, mechanical and chemical testing, microscopy and non-destructive imaging, failure analysis, polymer chemistry, polymer physics, and polymer processing. I have experience in evaluation and testing of the physical properties and durability of polymers, in the determination of the formulation and chemistry that control these properties, and in the selection and specification of polymers for different applications. I have experience formulating and evaluating polymer compositions, testing their properties and assessing chemical compatibility. I have been directly involved in product development, product line extensions, transfer of new products to manufacturing, qualification of alternative materials and manufacturing equipment, evaluating customer complaints, and performing root cause investigations. I have lectured on the topics of material selection, plastics failure analysis, and chemically-enhanced failures. I am an active member of

two Underwriters Laboratory Standard Technical Panels, STP 746 (Polymeric Materials) and STP 758 (Appliance Wiring), and the UL task force on Long Term Thermal Aging.

My *curriculum vitae* is provided in Appendix A. A list of previous testimony is provided in Appendix B.

2.2 Information Considered

In the course of this analysis, Exponent has reviewed and relied upon documents, testimony, and examination and testing of physical items. A list of materials considered is provided in Appendix C.

Although I have not prepared trial exhibits at this time, I may use any and all of the information described or referenced in this report. Additionally, I may use existing materials for demonstrative purposes.

2.3 Compensation

Exponent currently charges a rate of \$710 per hour for my time. Additional Exponent staff members with lower billing rates have assisted me in this project. No portion of our compensation is dependent on the outcome of this matter.

3 Summary of Opinions

Based on the information available to me, and my education, training and experience, I hold the following opinions regarding PCBs in and around the city of Spokane, WA to a reasonable degree of scientific certainty:

- PCB plasticizers were selected for use in materials because of a unique and desirable combination of properties, including stability, inertness, chemical compatibility, low water solubility, and low volatility.
- Monsanto provided appropriately comprehensive and relevant information to enable formulators to evaluate PCBs. The information provided by Monsanto allowed direct evaluation as well as evaluation in comparison to other plasticizers in compositions intended for various end uses according to industry standards and other methods reflected in the literature as well as methods proprietary to the formulating company.
- Monsanto was not the formulator of any material incorporating PCBs as an additive, including caulks, sealants or industrial paints produced or sold into the market. Monsanto manufactured PCBs that were only one component of the end use material into which they were formulated, and therefore Monsanto could not reasonably know the composition, properties, or specific end use conditions anticipated for the materials formulated by its customers.
- PCBs, while integral to many industries, comprised only approximately 1% to 1.5% of the total plasticizer market from the mid-1950s through 1970.
- PCBs were unique materials, with unique chemical structure-property relationships important to function. When Monsanto withdrew PCB plasticizers from the market, there was no one-to-one replacement, such that products made with PCBs had to be discontinued or reformulated to have different properties and characteristics.
- PCBs were integral to the United States military and the war effort for World War II. Polysulfide sealants, which typically required PCBs to achieve their properties were directly required in military specifications. When Monsanto discontinued PCB for

plasticizer use, formulated products that were previously qualified were unable to achieve the specifications.

- PCBs were one of the most important materials in the development of high performance caulks and sealants for the construction industry, aircraft, automobiles and a variety of other applications. They also enable specific performance in industrial paints and coatings.
- Polysulfide sealants that required PCB plasticizers to achieve their properties were integral to many industries, including the construction, aircraft, automotive, and marine industries in the 1940s through the 1970s. They were directly required in building specifications, federal specifications and military specifications.
- Release of PCBs from caulks, sealants, or paints would depend on formulation as well as end use conditions (e.g., temperature, air circulation, and exposed surface area), which could not reasonably be defined or controlled by Monsanto.
- To the extent PCBs were released from caulks, sealants, or paints, the release would have occurred more rapidly at the time of application and shortly thereafter, and surface depletion over time would further reduce PCB release rates. Further, to the extent PCBs were released from these materials, the lower chlorinated homologs are more likely to be released than the higher chlorinated homologs due to their higher vapor pressure.
- Any caulks, sealants, or paints still in use at the time of this lawsuit would be past their useful life and should have been replaced through regular maintenance regardless of composition.
- Not all PCBs present in formulated compositions are due to the intentional addition of Aroclor plasticizers. Certain congeners may be present from other chemical sources such as the addition of specific dyes or as the by-product of manufacturing processes.

4 Background

Polychlorinated biphenyls (PCBs) are synthetic compounds produced in the United States between 1929 and 1977, although they were only available until 1970 as a plasticizer. Mixtures of the molecules, which consist of a biphenyl structure with 1 to 10 chlorine atoms attached to the phenyl rings, were used as dielectric fluids for transformers and capacitors as well additives for property enhancement in materials such as caulks and sealants.

Plaintiffs allege that Monsanto-manufactured PCBs migrated from their original source to surrounding areas, and contaminated these areas with excessive PCBs. They further allege that Monsanto's conduct caused and continues to cause harm to the City of Spokane.

In the report that follows, I provide an overview of Monsanto's relationship to the formulated PCB-containing products found in and around Spokane and the alleged exposures by describing Monsanto's PCB plasticizers (i.e., Aroclors), Monsanto's role as a component supplier to formulators, how plasticizers are used in building materials such as caulks and sealants, and factors impacting performance and durability of these materials. I also provide a response to plaintiff's allegations related to PCB plasticizers.

4.1 Monsanto Company

Since the early 1900's, Monsanto produced a variety of chemicals for industry, a portion of which were used as additives within the plastics industry. In 1935, Monsanto acquired the PCB manufacturer Swann Chemical Company, allowing Monsanto to enter the commercial PCB market. PCBs were originally used mainly as a flame retardant dielectric fluid in transformers and capacitors but, as specific needs arose, a portion of the PCBs were sold to the plastics industry as a plasticizer under the trade name Aroclor.

Monsanto was a major plasticizer producer, offering a wide variety of chemistries and nearly 80 different plasticizers to industrial customers who would combine them with other components to

make a range of products.¹ A small portion of Monsanto's plasticizer offerings were Aroclors. These were low cost specialty chemicals² representing approximately 1% of the total plasticizer market in the 1950's and 1960's.³ As a supplier of bulk raw materials, Monsanto did not sell Aroclors as end use products. Instead, they were sold to other manufacturers as additives for property modification of plastics in accordance with those companies' product and market needs. In other words, Monsanto's customers for Aroclors and other Monsanto plasticizers were chemists and formulators responsible for developing materials for a range of uses and industries.

As was customary and expected in the chemical industry, Monsanto provided technical information related to the properties of the raw materials it produced in their pure, non-formulated forms to its customers.⁴ For plasticizers such as Aroclors, this information included physical and chemical data such as density, compatibility, vapor pressure, boiling point, compatibility, flash point, etc., as well as regulatory⁵ and industrial health information.⁶ The information could be used by Monsanto's customers, or more specifically their formulators, as a guide for their own product development. Monsanto also offered access to internal knowledge of Monsanto's broad plasticizer product lines in the form of its Plasticizer Council, a technical service described as providing fundamental knowledge and insight into which of Monsanto's many plasticizers may be applicable for potential uses. Combined, the Plasticizer Council and product brochures offered a wide range of experience and knowledge that aided customers in navigating the large selection of plasticizers and related materials offered by Monsanto.

Monsanto's expertise related to its own products assisted formulators in narrowing options and supplementing their own existing knowledge from other suppliers and their own research, but in no way directed or determined the actual formulations to be used by Monsanto customers. Proper formulation was governed by the material manufacturers and confirmed through testing

¹ For example, Modern Plastics Encyclopedia Vol. 48: No. 10A October 1971, Plasticizers Chart p.653 – 664 and Suppliers Index p.707.

² Preuss HP, Paint Additives, Noyes Data Corporation, Park Ridge, NJ, 1970, p. 35

³ US Tariff Commission - Synthetic Organic Chemicals - US Production and Sales, 1958-1971 and ("Polychlorinated Biphenyls and the Environment", Interdepartmental Task Force on PCBs, Washington, DC, May 1972, COM-72-10419.

⁴ For example, Plasticizer Blue Book – 1969 MONS077721

⁵ For example; STLCOPCB4046288, MONS090481

⁶ For example; TOWOLDMON0001620, TOWOLDMON0001622, LEXOLDMON001172, LEXOLDMON001182

and experimentation. All formulation, acceptance testing, and sales of formulated products was performed or directed by Monsanto's customers.

Importantly, the chemical and physical properties of mixtures differ from those of pure raw materials. In some cases raw material suppliers, such as Monsanto, would provide sample formulations for generic products to aid in guidance and to demonstrate compositional effects of additives on final product performance. These formulations were not commercial products but could be used by formulators as high-level demonstrations of different additives and plasticizers for broad uses.

Formulators rely on technical education, experience, end-use testing, and other information specific to the intended final product as well as an understanding of anticipated end use conditions for the final product when selecting and evaluating raw materials for use. Monsanto's customers determined the types, amounts, usage, co-ingredients, and overall formulation of the end-use products (e.g., caulks and coatings) that these product-creating customer were selling to finished goods customers. Monsanto did not provide commercial formulations to their customers, and could not reasonably predict the chemical or physical behavior of the vast number of commercial products that might include Aroclor as a plasticizer.

4.2 Aroclors

Aroclors are one trade name for a family of PCBs and PCTs.⁷ A PCB is a molecule containing two joined benzene rings (a biphenyl) with a varying number of chlorine atoms attached. Because of the chemical structure of the biphenyl ring, an example of which is shown in Figure 1, a PCB can contain 1 to 10 chlorine atoms. The chlorine atoms can be arranged along the biphenyl ring in various configurations, and each combination exhibits specific chemical properties associated with the structure. There are 209 unique combinations of the number and arrangement of chlorines, which are referred to as congeners. Congeners containing the same number of chlorines (i.e. having the same molecular weight) are referred to as homologs. Table 1 lists the chemical formula, molecular weight, and number of congeners of the various PCBs.

⁷ PCTs are polychlorinated terphenyls and therefore contain an additional benzene ring compared to PCBs.

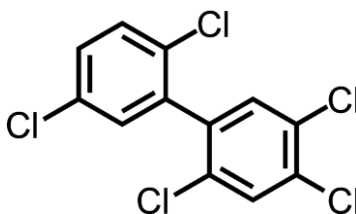


Figure 1. Chemical structure of a polychlorinated biphenyl

Table 1. Empirical formula, molecular weight, and number of homologs for each PCB.

Empirical Formula	Homolog MW (g mol ⁻¹)	# Congeners With This Formula
C ₁₂ H ₉ Cl	189	3
C ₁₂ H ₈ Cl ₂	223	12
C ₁₂ H ₇ Cl ₃	258	24
C ₁₂ H ₆ Cl ₄	292	42
C ₁₂ H ₅ Cl ₅	326	46
C ₁₂ H ₄ Cl ₆	361	42
C ₁₂ H ₃ Cl ₇	395	24
C ₁₂ H ₂ Cl ₈	430	12
C ₁₂ HCl ₉	464	3
C ₁₂ Cl ₁₀	499	1

4.2.1 Aroclor Uses

Aroclors, which were sold as a mixture of congeners with a specific 4-digit naming system,⁸ were initially recognized for their use as flame retardant insulating fluids in transformers and capacitors. However, due to the flame retarding properties of the material, combined with other beneficial attributes including low vapor pressure, miscibility with a wide range of materials, adhesive promotion, and thermal, chemical, oxidation, weather, mold and water resistance, the Aroclor family of compounds found use as additives in certain plastics to impart specific properties desired by formulators for particular applications. Moreover, Aroclors were known to impart substantial improvements in extending cure time for certain compositions, making

⁸ Within the naming convention, the first two digits described the molecule type and the second two digits described the weight percent chlorine. Thus, the 1200 series indicated only biphenyl rings, the 2500 series indicated a blend of 75:25 biphenyl:triphenyl, the 4400 series indicated a 60:40 biphenyl:triphenyl mixture and the 5400 series indicated all triphenyls. For example, Aroclor 1254 consisted of all biphenyl rings and contained an average of 54% by weight chlorine.

previously difficult to work-with building materials much more available to the construction industry.⁹ Aroclors were used as a plasticizer to modify physical, chemical, and durability performance in paints, coatings, caulks, sealants, and bulk plastics.

In the United States, Aroclors were used in industrial paints and coatings because of their valuable attributes such as compatibility, low volatility, low water solubility, heat stability and fire retardant properties and antimicrobial resistance. They were not, however, recommended for use as household paints.¹⁰ Further, despite the unique uses of Aroclors, they were not used in food packaging¹¹ or in food contact processes,¹² and no documents exist showing PCBs were used in chewing gum, delustering of rayon or as a plasticizer in shower curtains.¹³

4.2.2 Aroclor Technical Information and Properties

Monsanto offered nearly 100 different plasticizers and related materials in the 1960s,¹⁴ only 8 of which were PCB- containing Aroclors.¹⁵ To aid customers and formulators in determining which plasticizers may be appropriate for each application, Monsanto provided many technical bulletins describing the uses and properties of all their manufactured plasticizers, including their Aroclor line of plasticizers. This information could also be found in the published literature of the time.¹⁶ Information presented in these bulletins included the chemical make-up of the plasticizers (the Aroclors were identified as chlorinated biphenyls and chlorinated polyphenyls) as well as information on density, vapor pressure, solubility, corrosivity, dielectric properties, flammability, and toxicity, among other attributes.¹⁷ Aroclors were unique and specialty

⁹ US Patents 3,331,782 and 3,455,854

¹⁰ MONS 0951888-MONS 095191 – as stated in these documents, Monsanto or the paint manufacturer could not completely control the use of paints, such as application method or applying on heated surfaces, and thus did not recommend Aroclors for any household paints.

¹¹ STLCOPCB4046288, MONS090481, – as early as 1940 Monsanto directly told customers that Aroclors were not approved by the FDA for food contact, while specifically directing customers to other additives that were approved by the FDA

¹² DSW579874

¹³ While Monsanto did have at least one advertisement depicting a shower curtain, this and similar advertisements were not directed at formulators or other technical decision-makers. All available technical and business documentation that reference vinyl shower curtain formulations indicate that only phthalate plasticizers were used for this purpose.

¹⁴ MONS080640 – Monsanto Plasticizers

¹⁵ MONS077721 – MONS077781, (MONS077728-MONS077730) The Plasticizer Blue Book

¹⁶ For example: Buttrey DN, Plasticizers, Franklin Publishing Company, Palisade New Jersey, 1960

¹⁷ MONS071574-MONS071603 – The Aroclors Compounds

plasticizers. No direct, one-to-one replacement existed for most applications that utilized Aroclors.

Information was also available from Monsanto,^{18,19} as well as in the published literature,²⁰ describing the volatility of materials formulated with PCBs (i.e., weight loss as a function of temperature and time). Federal specifications required weight loss tests as early as the 1960's²¹, and Monsanto collaborated with large clients such as Thiokol in evaluating properties such as weight loss.²² These literature sources and documents demonstrate that formulators recognized the need to independently test individual formulations for properties of the bulk material, and not to simply rely on the properties of individual components of a formulation to determine the overall formulated material properties.

Aroclors were industrial chemicals, sold to customers familiar with chemical technology. When Aroclors were sold to formulators, they were accompanied not only by associated technical data regarding properties, but also warnings explaining potential risks associated with use. Monsanto included recognizable warnings and similar relevant information related to Aroclors consistent with the chemistry and customer.^{23,24} In addition to this information, Monsanto also reminded end users that formulations and testing provided by Monsanto was specific to the materials used in their testing and that individual formulators would need to independently evaluate their own formulated materials.²⁵

¹⁸ Monsanto Letter Dated February 12, 1969, Thiokol Work Request 69-22, Priority A; HARTOLDMON0029396 – HARTOLDMOND0029404, Polysulfide Modifiers, Special Report from Monsanto Research

¹⁹ Scientists at Monsanto were well known as experts in plasticizers and published regularly in the literature. For example, JR Darby and JK Sears, Encyclopedia of Polymer Science and Technology, vol 10, 1969, and JR Darby and JK Sears, The Technology of Plasticizers, 1982

²⁰ For example, Doolittle AK, The Technology of Solvents and Plasticizers, John Wiley and Sons, New York, New York, 1945; Mellan I, Industrial Plasticizers, The Macmillan Company, New York New York, 1963; Mellan I, Plasticizer Evaluation and Performance, Noyes Development Corporation, Park Ridge, New Jersey, 1967; Kirk-Othmer Encyclopedia of Chemical Technology, 2nd Edition, Vol 15, John Wiley and Sons, 1968

²¹ Federal Specification TT-S-230A, Dated 2/3/1964

²² HARTOLDMON0029396 – HARTOLDMOND0029404, Polysulfide Modifiers, Special Report from Monsanto Research

²³ For example: LEXOLDMON001172, LEXOLDMON001189, LEXOLDMON001190

²⁴ For Example: The Aroclors, Physical Properties and Suggested Applications – MONS080132-MONS080153 (specifically p. MONS080153); Aroclor Compounds Specialty Data Report, 1963 - 0509197-0509207 (specifically p. 0509207); The Aroclors, 1953 – MONS071714-MONS071740 (Specific Page MONS071733)

²⁵ For Example: Polysulfides Special Report from Monsanto Research, HARTOLDMON 00292396 - HARTOLDMON00292404 (Specific Page HARTOLDMON0029402); Aroclor Compounds Specialty Data Report, 1963 - 0509197-0509207 (Specifically Page 0509197)

4.2.3 Historical Sales and Growth of Polymers and Plasticizers

Sales of polymers and plasticizers were increasing at a rapid rate in the 1900s, especially after mid-century.²⁶ For example, between 1960 and 1969 sales of polymers within the United States increased over 150%, from approximately 8.7 billion lbs in 1960 to over 23 billion lbs in 1969 (Figure 2).³ Plasticizer demand, and subsequent sales, increased similarly from 600 million lbs to 1.4 billion lbs,³ an increase of approximately 130%.

To keep up with increasing demand and increasing uses of polymers, the number of plasticizers offered by chemical suppliers increased rapidly during this time. In 1960, 70 different companies reported selling over 880 plasticizers in the US, but by 1969 at least 85 different companies reported selling over 1360 plasticizers. However, the number of Aroclor PCB plasticizers did not increase over the same time period. Despite their unique properties, Aroclors were only a specialty plasticizer, accounting for only slightly more than 1% of total plasticizer sales in the US during this time (Figure 3).³

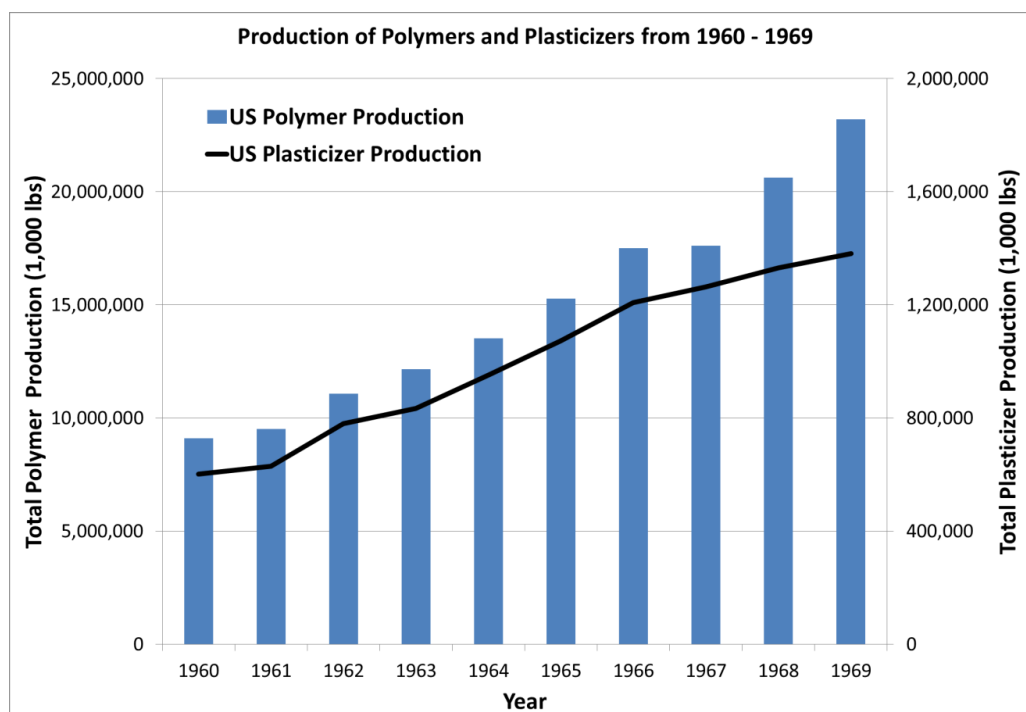


Figure 2. Polymer and plasticizer production in the US (all manufacturers and all types) between 1960 and 1969.

²⁶ JR Darby and JK Sears, Encyclopedia of Polymer Science and Technology, Vol 10, 1969

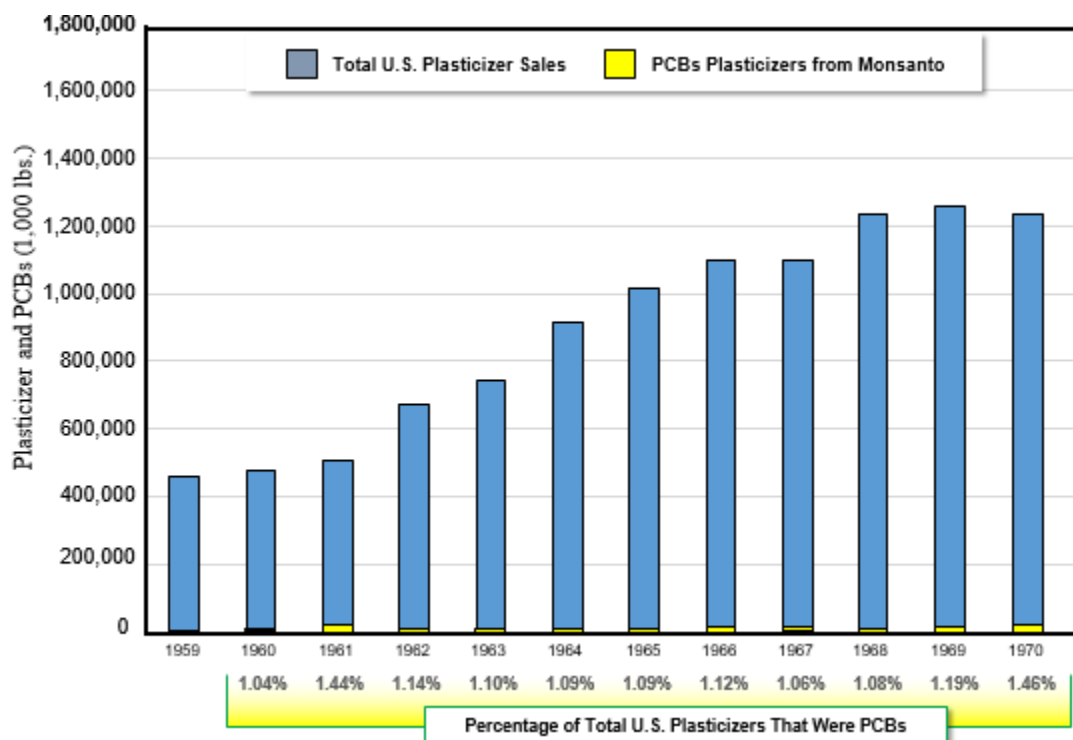


Figure 3. Total plasticizer sales and total PCB Plasticizers sold by Monsanto per year

4.2.4 Aroclor Properties

Aroclors were chosen by formulators for their unique blend of properties including low volatility, high solubility in many resins, flame retardance, adhesion promotion, resistance to weathering, chemicals, mold and other aging factors including UV and moisture, and their general ability to provide synergistic property enhancements.

4.2.5 Vapor Pressure

Aroclors are comprised of a variety of PCB homologs, which, due to their differing molecular composition, have different individual vapor pressures. In general, lower chlorinated homologs will have higher vapor pressures than the more highly chlorinated homologs. When reporting vapor pressures of Aroclors, Monsanto and other researchers reported estimated or extrapolated values from data obtained at a higher temperature, in accordance with generally recognized

testing methods. Because chemical concentrations associated with materials having low vapor pressures are historically difficult to measure,²⁷ estimations and extrapolations from higher temperature data were used.

Monsanto provided vapor pressure information for formulators' consideration in material selection.²⁸ Using Aroclor 1254 as an example, vapor pressure values provided by Monsanto generally ranged from 10^{-4} to 10^{-5} mmHg at 100°F. The low end of these reported vapor pressures have been validated in recent years.²⁹ In the eyes of a formulator, the difference between these very low values would be considered insignificant, as pure component properties were only used as initial selectors for finding potential formulation materials. As stated in Organic Coating Technology "...the temperature at which a plasticizers boils under atmospheric pressure or at a reduced pressure is not a satisfactory criterion of the volatility of a plasticizer from the composition in which it is used."³⁰ As discussed in more detail in section 4.3, using pure material properties, such as vapor pressure, is a poor method to understand how a material will perform or behave in a formulation.

4.2.6 Water solubility

Aroclors have inherently low water solubility due to the chemical properties of the biphenyl ring and associated chlorines. Their solubility in water ranged from 50-200 ppb (0.050 – 0.2 ppm), far lower than many other plasticizers on the market at the time. Monsanto recognized the need for testing of Aroclors to quantify their low water solubility,³¹ and selected results from their testing are summarized in Table 2. For comparison, solubility data for selected organic compounds, including other plasticizers offered by Monsanto, are also provided in Table 2.

²⁷ Jacobs, MB, The Analytical Chemistry of Industrial Poisons, Hazards, and Solvents, Interscience Publishers, Inc, NY NY, 1949

²⁸ For example: The Aroclors, Application Data Bulletin No. P-115, MONS 071714,

²⁹ Values for Aroclor 1254 vapor pressure were obtained by independent researchers in the 2000s and reported values of 3.7×10^{-5} and 8.2×10^{-5} . (Nakajoh, K., et al., Measurement of Temperature Dependence for the Vapor Pressures of Twenty-six [PCB] Congeners in Commercial Kanechlor Mixtures by the Knudsen Effusion Method, Environmental Toxicology and Chemistry, 25(2):327-326. & IARC, Polychlorinated and Polybrominated Biphenyls, Volume 107, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Lyon, France, 513 pp.)

³⁰ Organic Coating Technology, Vol I, Oils, Resins, Varnishes, and Polymers, John Wiley & Sons, NY, NY, 1954, p. 397

³¹ DSW372924, August 20, 1968.

Aroclors have limited water solubility, and their solubility decreases with increasing chlorine content.

Table 2. Comparison of Aroclor water solubility with selected other chemicals including other plasticizers offered by Monsanto

Compound	Water solubility at 25°C
Ethanol	Infinite, 25°C ³²
Acetic acid	30,900,000 ppb, 20°C ³³
Santicizer 8	1,300,000 ppb, 23°C ³⁴
Benzene	8,200 ppb, 22°C ³⁵
Santicizer 160	3,000 ppb, 30°C ³⁶
Aroclor 1242	203 ± 10 ppb, 25°C ³⁷
Aroclor 1248	106 ± 14 ppb, 25°C ³⁷
Aroclor 1254	50 ± 2 ppb, 25°C ³⁷
HB-40	Insoluble, 25°C ³⁸
DCHP (Dicyclohexyl phthalate)	Insoluble, 25°C ³⁹
DPP (Diphenyl phthalate)	Insoluble ⁴⁰

4.2.7 Use in Military Applications

Historical military specifications incorporated Aroclor PCBs either explicitly, or through the performance requirements that PCBs enabled.⁴¹ For example, Aroclors were used as a direct material standard⁴² (i.e. the Aroclor was used as the benchmark for performance) as well as a specified component of a standard composition⁴³ for certain high performance lacquers and paints. Aroclors were also required to achieve the necessary properties of certain qualified specialty coatings and wire insulation,⁴⁴ and they were the source of many of the required

³² Handbook of Chemistry and Physics, 35th ed., C.D. Hodgman (ed. in chief), 1953, pp. 912-913.

³³ Handbook of Chemistry and Physics, 35th ed., C.D. Hodgman (ed. in chief), 1953, pp. 696-697.

³⁴ Modern Plastics Encyclopedia, 1948, Plasticizers chart.

³⁵ Handbook of Chemistry and Physics, 35th ed., C.D. Hodgman (ed. in chief), 1953, pp. 754-755.

³⁶ Modern Plastics Encyclopedia, 1950, p. 1066.

³⁷ DSW202957, November 11, 1969.

³⁸ Modern Plastics Encyclopedia, 1948, Plasticizers chart.

³⁹ Modern Plastics Encyclopedia, 1962, p. 62.

⁴⁰ Modern Plastics Encyclopedia, 1945, p. 221.

⁴¹ For example: MIL-S-8784A, November 1956; MIL-S-11030C, July 1963; MIL-C-18255A(Ships), October 1959; MIL-S-7502C(ASG), July 1959; MIL-S-8802D, April 1961; MIL-L-7146A, November 1964

⁴² MIL-L-7146A Lacquer; Hydraulic Fluid Resistant (For Interior Aircraft Use) November 1964

⁴³ PCB-ARCH0451797-0451806, PCB-ARCH0483759-0483759

⁴⁴ PCB-ARCH0480180

characteristics of commercial polysulfide sealants.⁴⁵ Indeed, in WWII the United States Secretary of War deemed that Monsanto, the sole-producer of Aroclor PCBs, as “...necessary in the interests of national defense.”,⁴⁶ and the U.S. government awarded Monsanto commendations for the manufacture and supply of raw materials such as PCBs to the government.⁴⁷ Documents reflect the fact that once Aroclor PCBs were discontinued, suppliers could no longer provide the qualified products to the military, which in at least some cases resulted in a government shipment directive and priority rating for Aroclors, again for the purpose of national defense.⁴⁸ Even after Monsanto discontinued Aroclors for plasticizer use, the United States government ordered Monsanto to sell Aroclors to select contractors for this purpose.⁴⁹

4.2.8 Monsanto Customers for Aroclors

Monsanto’s plasticizer customers, including their Aroclor customers, were highly sophisticated in scientific knowledge and practice, and capable of understanding the value and limitations presented in Monsanto’s technical literature through the normal training and experience associated with their scientific positions. Indeed, Monsanto’s customer list reflects a large group of technologically and scientifically sophisticated companies, including some of the largest companies focused on chemical research in the world, such as Dow Chemical and E.I. DuPont de Nemours, as well as medium and smaller companies, such as W.R. Grace, Products Research Corporation (PRC) and Amercoat. Each of these companies employed a research staff consisting of employees who would have been trained in the principles associated with properties of formulation.

⁴⁵ Aroclors generally offered better compatibility, stability, and pot life than alternative plasticizers for polysulfides, though some specifications allowed for other formulations.

⁴⁶ HAGOV0001391-HAGOV0001403

⁴⁷ HAGOV0000159, HAGOV0000160, HAGOV0000192-HAGOV0000194

⁴⁸ STLCOPCB0022822, STLCOPB0022820, STLCOPCB0022837, STLCOPCB002811

⁴⁹ Letter from the US Department of Commerce to Monsanto, Dated November 14, 1972; Response letter from Monsanto to the Department of Commerce, Dated November 17, 1972 (PCB-ARCH0504468-PCBARCH0504470); Letter from the US Department of Commerce to Monsanto, Dated July 24, 1974; Response form letter from Monsanto to the US Department of Commerce (PCB-ARCH0504400)

Many of the companies employed one or more Directors of Research and numerous scientific and technical researchers. (See Appendix D⁵⁰) For example, Dow chemical listed 650 trained research personnel, such as chemists, engineers and physicists and an additional 500 support personnel who performed research and development activities within the company in 1946⁵¹. By 1960, the number of R&D personnel at Dow had nearly doubled to approximately 2,000⁵². W.R. Grace listed 2 Directors of Research Services, 125 chemists, 102 technicians, 72 auxiliaries in their R&D program in 1960, and Amercoat Corporation listed 9 chemists, 1 engineer, and 8 additional personnel as their research staff.⁵² Each of these companies not only maintained a research staff of formally trained scientist and engineers, but public information confirms that they relied on this expertise to develop products based on relevant scientific and engineering principles. Amercoat Corporation, for example, was granted at least 6 United States patents focused on the coating and adhesive markets between 1960 and 1970 alone.⁵³ Products Research Group was granted at least 3 patents on polysulfide resins between 1957 and 1966,⁵⁴ and companies such as Dow Chemical and DuPont were granted hundreds or more patents related to resins, coatings, plasticizers and other related compounds between 1930 and 1970. Thus, the public record also confirms that Monsanto's customers were independently and uniquely developing formulated materials for use in the commercial marketplace

Distribution of intermediate materials, such as plasticizers, to these customers and then into the overall market followed many routes, eliminating the ability for a company to know all of the end users or uses of such a product. A plasticizer, such as a PCB, may be sold by Monsanto to a distributor, which would then be sold to a formulator; the formulator may then sell the product to a wholesaler or distributor, who would then sell the product to the end user.⁵⁵ This process of transfer and modification by subsequent commercial entities is generally described as the supply

⁵⁰ Appendix D contains some of Monsanto's Aroclor customers, specifically ones that were focused on areas that included plasticizer and other polymeric additive uses. Companies were obtained from incomplete historical Monsanto sales data. For a list of sales documentation used in the development of Appendix D, see the Materials Considered list under the heading 'Monsanto Sales Data'.

⁵¹ Industrial Research Laboratories of the United States, National Academy of Sciences, National Research Council, publication 844, 8th edition (1946)

⁵² Industrial Research Laboratories of the United States, National Academy of Sciences, National Research Council, publication 844, 11th edition (1960)

⁵³ US Patents 2944919, 2952562, 2998269, 2998328, 3491045, 3615730

⁵⁴ US Patents 2787608, 2964503, 3225017

⁵⁵ Deposition of Robert Kaley, Dated April 5, 2016, pp. 60-62.

chain, and can include many steps and routes, as well as proprietary transformations.⁵⁶ Thus, the manufacturer of the intermediate raw material would have no way to know where the final product was being used, or specifically how its material was incorporated in that final product. As a practical matter, Monsanto could not know the total number of uses or formulations where its products were used. It would not be feasible for Monsanto to be aware of all the uses of Aroclors, let alone understand all of the end applications for which Aroclors were used. Further, Monsanto would not have the resources, time or ability to provide formulations and testing to all these customers.

4.3 General Formulation Principles and Knowledge

Chemistry, physics and engineering textbooks in the 1940s-1970s discussed general formulation principles as well as individual properties a formulator must understand when creating a formulation, such as vapor pressure, solubility, and cure rates (need a time frame). Thus, those educated in the relevant fields would have appropriate baseline knowledge to understand the physical and chemical properties of formulation components.

The major disciplines that educated individuals who moved to careers in formulation were chemistry, physics and chemical engineering. Each of these disciplines have specific focus and associated learning materials, but all provided the same basic knowledge for material properties. Using vapor pressure as an example, Langes Handbook of Chemistry,⁵⁷ a seminal reference text of chemistry, Thermodynamics by Enrico Fermi in Physics,⁵⁸ and Perry's Chemical Engineering Handbook,⁵⁹ the main reference text for chemical engineers, all provided descriptions and knowledge of vapor pressure to their respective disciplines that vapor pressure is never truly zero. Each text clearly indicated vapor pressure is a temperature dependent phenomenon that is positive for all values of temperature (i.e. all materials have a vapor pressure, even if they can't

⁵⁶ Gardner JT, Cooper MC, Strategic Supply Chain Mapping Approaches, Journal of Business Logistics, Vol.24, No.2, 2003

⁵⁷ Lange, N, Lange's Handbook of Chemistry, Handbook Publishers, Sandusky Ohio, 1946 – This textbook discusses the Clausius-Clapeyron relation, which is a mathematical description of the relationship between temperature and vapor pressure and demonstrates how vapor pressure is never zero.

⁵⁸ Fermi E, Thermodynamics, Prentice Hall Publishing, 1937 – This textbook provides equations of vapor pressure with relations to thermodynamics and show that vapor pressures are non-zero.

⁵⁹ Chemical Engineers' Handbook, 2nd edition, John H. Perry (Ed.), 1941- This book contains boiling points of certain PCBs, presents Clausius-Clapeyron and provides methods for estimating vapor pressure of pure substances. All of these aspects show how vapor pressure is never zero for a material.

be measured.) Thus, students and formulators of the time were all aware that no liquid or fluid-like material has a truly zero vapor pressure, and the idea of non-volatile vapor pressures was meant for as being relative to specific applications.

Publications investigating the possible toxicological aspects of chemicals understood and demonstrated that vapor pressures of materials, especially liquids, were non-zero, and that measuring low vapor pressures during the time period was difficult. As a result of the difficulty of measuring low vapor pressures, such as those of Aroclors, estimation methods were often employed.⁶⁰

Measurements and understanding of individual properties of materials were discussed at length in these scientific disciplines, but the combination of many components into a formulation for a functional material can be much more difficult for end-property determination. During the time PCBs were manufactured, it was well known that the properties of an individual material would not be the same when formulated into a mixture. As aptly stated in Organic Coating Technology, Vol I, Oils, Resins, Varnishes, and Polymers regarding working with plasticizers;⁶¹

“...the temperature at which a plasticizer boils under atmospheric pressure or at a reduced pressure is not a satisfactory criterion of the volatility of a plasticizer from the composition in which it is used. Actual loss in weight measurements from the composition must be made, but since these would take too long at normal temperatures, an elevated temperature is used. ...elevated temperature constitutes an accelerated test which may not give the same relative values for the behavior of a series of plasticizers aged at room temperature; however, it is the best compromise we have at present.”

This text goes on to discuss many of the other issues associated with formulation development specific to plasticizers, such as plasticizer exudation, migration and extraction. Clearly formulators of the time were aware that individual component properties were merely a starting point for material selection in formulation development. Further, final products must be tested for important characteristics; relying only on individual component properties would be insufficient for characterizing the performance of final materials that were commercially available to end users.

⁶⁰ Jacobs, MB, The Analytical Chemistry of Industrial Poisons, Hazards, and Solvents, Interscience Publishers, Inc, NY NY, 1949

⁶¹ Organic Coating Technology, Vol I, Oils, Resins, Varnishes, and Polymers, John Wiley & Sons, NY NY, 1954

4.4 Caulks and Sealants

Caulk is a term for elastomeric compositions used to fill gaps and seal joints or seams in structures. Caulks are provided by manufacturers in a pourable or easily extrudable form, typically in accordance with one or more standard specification. Upon curing, the caulk adheres to the adjacent substrates and forms a barrier. In present industry, caulk is most commonly used in building construction wherever a structural unit requires thermal insulation, control of water penetration, and noise mitigation.⁶²

Each additive incorporated into the formulation has a particular function to impart desired material properties to the sealant, though these additives may provide synergistic or antagonistic effects. Fillers are a common additive used to control properties such as structural integrity, refractive index, cost, and color control.⁶³ A second common additive is a plasticizer. A plasticizer is defined as an additive that increases plasticity or fluidity of a material – as such, the number of materials available for use as a plasticizer for caulking/sealant applications are vast.⁶⁴ Plasticizers are primarily used to reduce embrittlement and prevent chipping/flaking; however, other properties, such as improved adhesion, enhanced flow, pot life regulation, and increased flame retardant properties can also be imparted.⁶⁵ The plasticizer used can have an important effect on material durability and other attributes related to function and safety.

Caulks/sealants are used in multiple applications and the caulk performance standards vary depending on the application as well as environmental exposure. For each situation, a sealant is required to achieve different performance standards and the formulator must prioritize the desired properties and choose appropriate additives based on performance, cost, and the

⁶² K. L. Mittal, A. Pizzi, Handbook of Sealant Technology, CRC Press 2009

⁶³ Examples of commonly used fillers are carbon black, titanium dioxide, calcium carbonate, or silica. Sealants, Adolfas Damusis, Reinhold Publishing Corp. 1967.

⁶⁴ Handbook of Plastics by Simonds and Ellis p 251 lists the number of plasticizers to be close to 20,000 in 1943

⁶⁵ Plasticizers can increase film forming tendencies, soften the film, impart flow (improve gunning), allow for homogeneous blending all components, and regulate pot life US Patent #s 3276870, 3455854, 3267063.

synergistic effects of mixing with other additives. Formulations vary by type of ingredient and quantity of any given component relative to the curable polymer.^{66,67}

Literature available during the timeframe (e.g., approximately 1940-1970) demonstrates the range in industrial uses and caulking formulations available.⁶⁸ The number of additives used in a caulk/sealant and final formulation depends on the application and desirable physical properties, as well as the experience and preferences of the formulator. As such, the formulation may be as simple as a 4-component system, as complex as a 16-component system, or some other propriety combination.⁶⁹

The formulation of any commercially available caulk is determined by experienced employees (i.e., formulators) with training and skills relevant to the specific company selling the caulk. The manufacturers of the additives in the caulk, which are raw material suppliers such as Monsanto, are rarely aware of the formulation, and cannot reasonably predict the specific composition or behavior of the formulated end-use products. Raw material suppliers, such as Monsanto, would provide technical literature containing data associated with the pure form of their chemical product (i.e. density, compatibility, vapor pressure, boiling point, compatibility, flash point, etc.) for use by chemists and formulators intending to create company-specific combinations as part of development and production as a commercial end-use product.

4.4.1 History of Construction Sealants

Rudimentary sealants have been used throughout history, dating back to the earliest recorded times where natural materials such as grass and bitumen were used to seal openings in early

⁶⁶ For example, US Patent No. 3770678 states “A polysulfide latex based caulking composition consisting essentially of... (c) from about 50 to about 300 parts by weight per 100 parts by weight of total polymer solids in the composition of special purpose additives selected from the group consisting of fillers, plasticizers, whiteners, adhesive additives, and latex stabilizers.”

⁶⁷ US Patent 3,348,351

⁶⁸ For example, US Patent No. 3717617 states “The curable compositions of the present invention can also contain various types of inert materials commonly employed in polysulfide-based sealant and caulking compositions such as fillers, plasticizers, pigments, ultraviolet light stabilizers, cure accelerators, and the like. Representative examples of the above type of compounds include calcium carbonate, titanium oxide, silica, tris-(dimethylamino)phenol, carbon black, dibutyl phthalate, chlorinated hydrocarbons, sulfur, alumina, polyethylene, polystyrene, zirconia, and the like.”

⁶⁹ US Patent # 3282902, Sealants, Adolfas Damusis, Reinhold Publishing Corp. 1967

building construction, and tar was used to seal ships.⁷⁰ Eventually, formulations using natural oils like linseed oil were found to be useful as sealants and putties, although their serviceable lifespan was often only a few years.⁷⁰ Only when synthetic polymers were developed and commercially available were sealants capable of providing longer useful life, improved adhesion, and the increased joint movement capability necessary to facilitate construction of taller and lighter buildings.⁷⁰ Two-component polysulfide sealants were the first major sealants to penetrate the construction industry, and are considered to be an integral component of the development of curtain wall construction.⁷¹ As stated in the Handbook of Sealant Technology⁷¹:

Building sealants based on liquid polysulfide polymers came to the market in the late 1940s. They were the first high-performance elastic sealants to be commercialized. Their market introduction occurred at the beginning of curtain wall construction in the United States, which is often credited with creating the need for high-performance sealants. However, one could also suggest that the novel polysulfide sealant, which allowed a moving joint to be sealed successfully, enabled this new construction technique and led to the popularity of the curtain wall. The answer to the question of the driver or driven is not certain, but surely one could not exist without the other. In either case, in the 1950s, polysulfides became the sealant of choice in the new curtain wall construction, as well as in cars, trains, and planes.”

From use in curtain walls to use in sealing fuel tanks, the widespread adoption of polysulfide sealants was directly related to the formulation characteristics. By the early 1960s polysulfide sealants were available in one and two component formulations, with components such as plasticizers added to improve a range of properties. Because of solubility limitations, PCBs were virtually the only material available to plasticize polysulfide.⁷² As a result, almost all polysulfide sealants produced in the 1950s – 1970s contained between 5-30% PCBs as a plasticizer,⁷² although some formulations indicate as low as approximately 1.5% PCBs were used⁷³. PCBs also imparted other property enhancements including durability,⁷² fire retardancy,⁷⁴ adhesion,⁷⁴ easily modified mechanical properties,⁷⁴ and improved pot life.⁷⁵ Sealants were selected for these and other attributes. For example, one-component formulations allowed for ease of use,

⁷⁰ Handbook of Sealant Technology (2009), The History of Sealants, Klosowski J.M. and Wolf A.T., pp. 4-5

⁷¹ Handbook of Sealant Technology (2009), The History of Sealants, Klosowski J.M. and Wolf A.T., p. 9

⁷² Sealants in Construction, 2nd ed, (2016) Klosowski K., Wolf A.T. p. 198

⁷³ US Patent 3,282,902

⁷⁴ Chemical Materials for Construction, Maslow P, (1974) p. 228

⁷⁵ US Patent 3,331,782

but two-component formulations typically offered greater elongation and resiliency.⁷⁶ The utility and use of polysulfide is reflected in multiple federal and military specifications that required polysulfides for specific applications.⁷⁷

Meanwhile, alternative sealants available in the early 1960s such as silicones and polyurethanes, suffered from a range of undesirable attributes. For example, available silicone sealants produced sharp odors, caused corrosion on metallic surfaces, could lack adhesion and did not have equal joint movement properties compared to polysulfides.⁷⁸ Polyurethane sealants had shelf-life issues, were subject to discoloration after sunlight exposure, and were sensitive to moisture (e.g., rain or other excessive moisture could cause a polyurethane sealant to expand and froth, compromising the integrity of the joint).⁷⁸ Acrylic latex sealants were another material to enter the market in the 1960s; however, these sealants physically dried rather than chemically cured after application. These sealants hardened over time and did not have good durability or long-term performance.⁷⁹

Despite industrial research to find alternatives, the removal of PCBs from the market in 1970 affected the quality and functionality of available polysulfide sealants through the 1970s.⁸⁰ Due to the removal of PCB plasticizers from the market, as stated by Maslow, “compounders of polysulfide sealants have been hard put to find replacements for these plasticizers”.⁸¹ Chlorinated paraffins and phthalate esters were investigated as PCB replacements, but those materials introduced difficulties related to stability, miscibility, and volatilization.⁸² Even in the late 1970s, research was still underway to replace materials that imparted the same properties in

⁷⁶ Chemical Materials for Construction, Philip Maslow, 1974, tables on pages 184-187

⁷⁷ For example: MIL-S-8784A, Sealing Compound, Aluminum Integral Fuel Tanks and Fuel Cell Cavities, Low Adhesion, Accelerator Required, Dated May 24, 1956; MIL-C-18255A(SHIPS) Military Specification Calking Compound, Synthetic Rubber Base, Wooden Deck Seam Application, dated October 6, 1959; MIL-C-22804(SHIPS) Military Specification Cement, Sealing, Double Planking, dated February 15, 1961.

⁷⁸ Sealants in Construction, 2nd ed, (2016) Klosowski K., Wolf A.T. p. 5

⁷⁹ Sealants in Construction, 2nd ed, (2016) Klosowski K., Wolf A.T. p. 199

⁸⁰ For Example, see Chemical Materials for Construction, Maslow P, (1974) section 309; and Sealants in Construction, 2nd ed, (2016) Klosowski K., Wolf A.T., Chapter 9.2

⁸¹ Chemical Materials for Construction, Maslow P, (1974) p. 228

⁸² US Patent 4,189,407

polysulfide sealants as PCBs,⁸³ and the government was ordering Monsanto to sell Aroclors to certain military suppliers.⁴⁹ No one-to-one replacement was identified.

4.4.2 Aging of Caulks and Sealants

Caulks are formulated to achieve certain properties associated with application reliability, short term properties and longer term durability. However, caulks and sealants have finite lifetimes, which are generally determined by resistance to environmental exposure conditions (e.g., sunlight, moisture, temperature-driven expansion/contraction, etc.⁸⁴) and the overall stability of the formulation (e.g., separation, component loss by migration and/ or volatilization). Sealant lifetimes can also be affected by overcoating with paints or other materials (e.g., due to incompatibilities, or imposed damage from aging and cracking of the over-material.) Aging affects functionality, and once a sealant/caulk can no longer perform its function it should be replaced. For building caulk/sealants, failure is typically defined as the point when the seal allows moisture to penetrate due to cracking or debonding.⁸⁵

White and colleagues at the National Institute of Standards and Technology (NIST) have identified that “Predicting the service life of building joint sealants exposed to service environments in less than real time has been a need of the sealant community for many decades.”⁸⁶ Test methods have been around since the early 1900’s to investigate volatile compounds loss at accelerated temperatures⁸⁷ with results reported throughout the literature,⁸⁸

⁸³ US Patent 4,189,407

⁸⁴ AT Wolf, Durability of Building Sealants, Taylor and Francis Group 1997; AT Wolf, Durability of testing sealants, Dow Corning, http://www.dowcorning.com/content/publishedlit/durability_testing_of_sealants_10132004.pdf

⁸⁵ CC White et al, A Systematic Approach to the Study of Accelerated Weathering of Building Joint Sealants, Journal of ASTM International, Vol. 9, No. 5.

⁸⁶ CC White et al, Durability of Building Joint Sealants, Chapter 8 Service Life Prediction of Polymeric Materials 2009, pp 115-128

⁸⁷ Standard Test for Loss on Heating of Oil and Asphaltic Compounds, ASTM D 6-20, Adopted 1911; Tentative Method of Test for Volatile Loss from Plastic Materials, ASTM Designation D 1203-52T, Issued 1952

⁸⁸ For example, Doolittle AK, The Technology of Solvents and Plasticizers, John Willey and Sons, New York, New York, 1945; Mellan I, Industrial Plasticizers, The Macmillan Company, New York New York, 1963; Mellan I, Plasticizer Evaluation and Performance, Noyes Development Corporation, Park Ridge, New Jersey, 1967; Kirk-Othmer Encyclopedia of Chemical Technology, 2nd Edition, Vol 15, John Wiley and Sons, 1968; Buttrey DN, Plasticizers, Franklin Publishing Company, Palisade New Jersey, 1960

and more detailed accelerated aging methods are continually being developed and updated.⁸⁹

The primary reason for this difficulty is due to the synergistic effect that different environmental factors have on the degradation of a sealant/caulk. Because of this, even today, it is very difficult to predict the service life of a caulk/sealant compound based on its components.

White and colleagues further state that “Studies in the construction industry in the past few decades have shown a 50% sealant failure rate within 10 years and a 95% sealant failure rate within 20 years after installation.”⁹⁰ Reports identified by Exponent that address life expectancies and service lifetimes of caulks fall in line with these failure rates.⁹¹ Although there are likely a significant number of other examples in the literature, Table 3 highlights the breadth of applications where caulk is used as well as the diversity in performance. None of the sealants listed in this table have an upper bound life expectancy over 30 years.

⁸⁹ CC White et al, Durability of Building Joint Sealants, Chapter 8 Service Life Prediction of Polymeric Materials 2009, pp. 115-128

⁹⁰ CC White et al, A Systematic Approach to the Study of Accelerated Weathering of Building Joint Sealants, Journal of ASTM International, Vol. 9, No. 5

⁹¹ Sealants, Adolfas Damusis, Reinhold Publishing Corp. 1967 and Case study window sealing systems by Henkel AG & Co. KGAA (http://www.pcf-projekt.de/files/1298483592/pcf_henkel_sealant.pdf).

Table 3. Expected lifetimes of various caulks/sealants.⁹²

<i>Sealant type</i>	<i>Movement Accommodation Factor (%)</i>	<i>Character</i>	<i>Life expectancy (years)</i>	<i>Joint suitability</i>
Oil-based	10	Plastic	1–10	Perimeter pointing.
Butyl-based	10	Plastic	15–20	Concealed joints. (not UV resistant.)
Acrylic				
Water-based	15	Plastic	10–15	Internal joints, plaster cracks, etc.
Solvent-based	20	Plastic	15–20	Perimeter pointing, concrete, stone cladding, etc.
Polysulphide				
One-part	20–25	Elasto-plastic and elastic	20–25	Perimeter pointing, structural joints, stone cladding, etc.
Two-part	25–30	Elasto-plastic and elastic	20–25	Structural joints, stone and cladding, joints subject to early high movement.
Two-part high modulus	10–20	Elasto-plastic and elastic	20–25	Paving, traffic, floor joints, etc.
Polyurethane				
One-part	10–30	Elastic and elasto-plastic	20–25	Light cladding, curtain walling, structural joints, stone cladding etc.
Two-part	20–30	Elastic	20–25	Light cladding, curtain walling, paving, etc.
Silicone				
Low modulus	50–70	Elastic and elasto-plastic	25–30	Perimeter pointing, curtain walling, stone and concrete cladding, structural joints, etc.
High modulus	20–30	Elastic	25–30	Glazing, sanitary ware, etc.
Flexible epoxy	5–15	Elasto-plastic	10–20	Floor joints, traffic areas, etc.

⁹² Resealing of Buildings, a Guide to Good Practice, Oxford Brookes University 1994

4.5 Plasticizers in Caulks and Sealants

Plasticizer selection is but one choice of many that must be made by a formulator when developing a new material for a specific application. The complicated nature of formulation requires the knowledge of experienced personnel to control the material specifications being manufactured and sold to their customers. This is true regardless of the use of the end product.

4.5.1 Plasticizer Effects

Plasticizers are ubiquitously used in the polymer industry, and thousands have been commercially available since at least the 1940's.⁹³ The primary function of this additive class is to increase plasticity or fluidity of a material, though other material properties will be affected and these must be balanced. Specific formulations can be complex, depending on the desired combination of end product attributes and the interactions of the various components, and this is the basis for the wide range of products encountered in the sealants, adhesives, coatings and other plastics markets. Trade, technical and patent literature provides examples of the effects of plasticizer type and amounts on physical properties.

Table 4 and Figure 4, from a 1967 textbook, depict some of these effects for two types of sulfur-based sealant resins, one from Thiokol and the other from Diamond Shamrock. Table 4 shows the effect of different amounts of an Aroclor plasticizer on mechanical properties in a polysulfide sealant. Figure 4 then demonstrates the effects of different plasticizers within a similar material, polymercaptan.⁹⁴ These provide a comparative example of the substitution effect on four different physical properties in a formulation; the mechanical properties of the sealant are sensitive to overall formulation, both plasticizer concentration and type. Additionally, each property changes at a different rate depending on the plasticizer added. These three plasticizers were commercially offered by Monsanto and others during the time period in question.

⁹³ Handbook of Plasticizers, 2nd Edition, G. Wypych, Chemtech Publishing, Toronto 2012. Handbook of Plastics by Simonds and Ellis

⁹⁴ Polymercaptans have been described as an “intermediate between polysulfides and the polyurethanes” Sealants, Adolfas Damusis, Reinhold Publishing Corp. 1967 p. 196

Table 4. Effect of Aroclor concentration on physical properties of a polysulfide sealant (LP-2 polymer).⁹⁵

	1	2	3	4	5	6
LP-2 polymer	100	100	100	100	100	100
"Aroclor" 1254	—	10	20	30	40	50
"Witcarb" RC	50	50	50	50	50	50
C-5 catalyst	15	15	15	15	15	15
<i>Physical Properties on Cast Sheets, ASTM D-412-62T</i>						
Tensile strength, psi	575	475	400	320	250	150
300% modulus, psi	200	175	150	120	110	100
Elongation, %	750	700	650	600	570	560
Shore A hardness	49	40	36	32	28	25

⁹⁵ Sealants, Adolfas Damusis, Reinhold Publishing Corp. 1967 p. 181

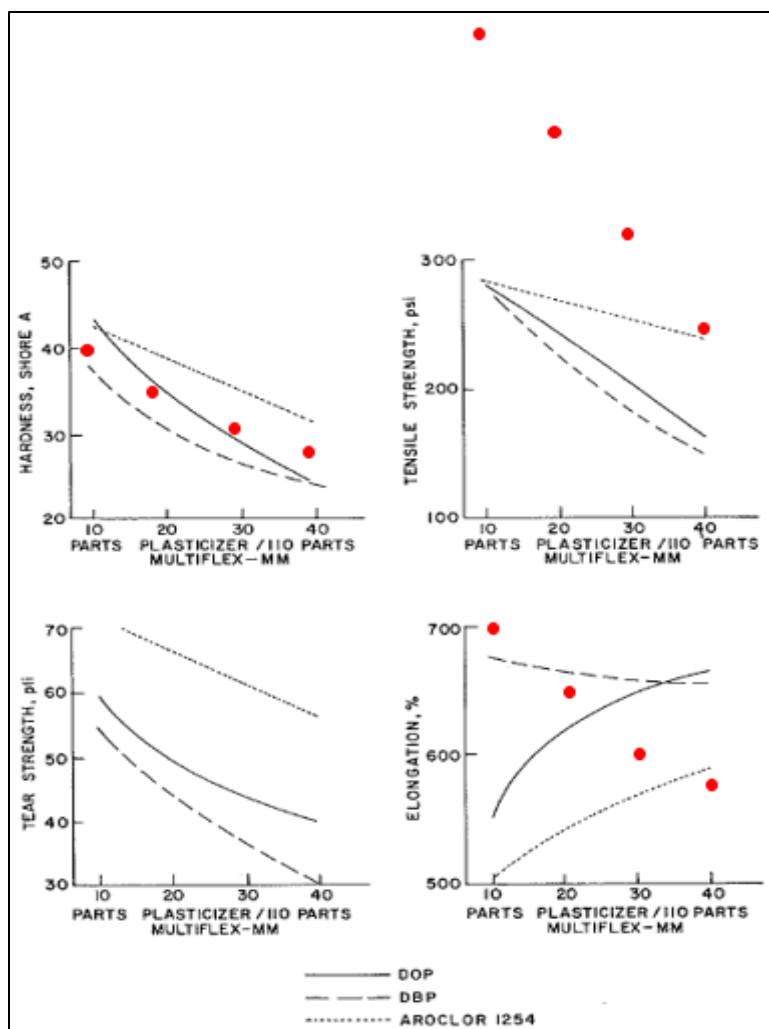


Figure 4. Effect of plasticizer concentration on initial mechanical properties of a polymercaptan based sealant, DMP-1002 (solid and dashed lines),⁹⁶ and the LP-2 polysulfide formulation (red circles) described in Table 4

Even with this type of information, a formulator would have to prepare candidate formulations to assess the full range of characteristics and determine which candidate formulation was appropriate for commercialization based on market or end customer requirements. For example, a formulator would still be expected to address other important characteristics of caulks, such as film forming tendencies, flowability related to application, mixture stability, pot life, adhesion to various surfaces, stability during high and low temperature cycling, resistance to chemical attack, leaching by water, oxidation, burning, fire spread, etc. A formulator would also be expected to assess longer term durability, as aging affects these properties to an extent that is related to the

⁹⁶ Sealants, Adolfas Damusis, Reinhold Publishing Corp. 1967 p. 205

environmental conditions encountered in use (e.g., heat, humidity, airflow, and sunlight) as well as component and formulation stability against these challenges. It is not unusual for formulations to appear similar in short term testing but differ significantly after aging.

4.5.2 Aging Effects

One effect of aging is associated with plasticizer loss, which leads to local hardening, embrittlement or other changes. Compatibility, vapor pressure, diffusion behavior and water solubility are factors that impact plasticizer loss, with higher compatibility, lower volatility or vapor pressure, slower diffusion and minimal external solubility (e.g., in water) leading to more stable compositions. PCBs exhibit a unique and desirable combination of these factors for minimizing plasticizer loss.

Volatility is a measure of how quickly a material will evaporate from a liquid composition to a gas, and depends on chemical structure and molecular weight, as well as interaction with the components of a formulation and interaction with the surrounding environment.⁹⁷ Typically, loss of plasticizer within a resin or formulated blend is slower than loss of plasticizer in a pure material.⁹⁸ The more complex the formulation, however, the more difficult it will be to predict the volatility of any individual component. Because the composition and use conditions affect volatility, the rate of evaporation of Aroclors in a sealant is dependent on formulation⁹⁹ and use conditions that are not and cannot be controlled by Monsanto. The need for formulators to test complete formulations and not rely on properties of individual components of a system was expressed by Doolittle¹⁰⁰ in his 1954 book;

“The determination of the volatility of the pure plasticizer from an open dish is of qualitative value, but evaporation from a plasticized resinous specimen is influenced so much by polymer-plasticizer attraction and by the rate of diffusion within the plastic mass that a true evaluation of volatility must be made by means of tests on plasticized specimens.”

⁹⁷ K Denbigh, *The Principles of Chemical Equilibrium*, Cambridge University Press 1981

⁹⁸ *Handbook of plasticizers*, 2nd edition, 2012 pp. 253-4

⁹⁹ HF Payne, *Organic Coating Technology*, Vol 1, 1954 Wiley.

¹⁰⁰ Doolittle AK, *The Technology of Solvents and Plasticizers*, John Wiley and Sons, New York, New York, 1954, p. 883

The rate at which a plasticizer migrates through a caulk is also specific to the type of caulk. Migration or diffusion of the molecules within the compound is affected by temperature,¹⁰¹ the initial concentration in the sealant/caulk, and, in many cases, interaction with fillers.¹⁰² The rate of plasticizer release is governed by both diffusion to the surface and subsequent removal from the surface. For a diffusion limited system, surface removal is reduced or prevented by a depleted surface region. As exemplified in Figure 5, the diffusion rate is formulation dependent and cannot be predicted based on the knowledge of a single component. Indeed the diffusion coefficient can vary by orders of magnitude using different base polymers.¹⁰³ Thus, a raw material supplier, especially an additive supplier, cannot reasonably predict diffusion behavior for an undefined formulation.

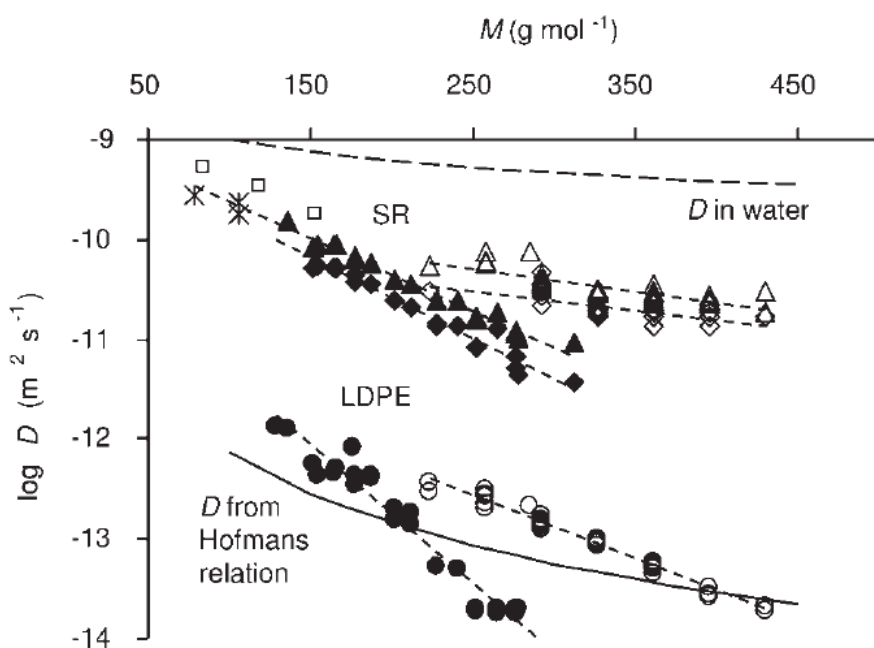


Figure 5. Diffusion coefficient of PCBs [open symbols] and polycyclic aromatic hydrocarbons (PAH) [closed symbols] in low density polyethylene (LDPE) and polysiloxane as a function polymer molecular weight.¹⁰⁴ Triangles [▲] and squares [■] represent polysiloxane, circles [●] represent LDPE.

¹⁰¹ Brandrup, Immergut, and Grulke, Polymer handbook 4th edition volume 2 Permeability and Diffusion Data, page VI-545, Table 3 Permeability coefficients of various organic compounds through low-density poly(ethylene)

¹⁰² Handbook of Plasticizers, Effect of plasticizers on other components of formulation – Plasticizer consumption by fillers. p. 187

¹⁰³ WR Brown, GS Park, J. Paint. Tech. 1970; 42:16. and AC Newns, J. Poly. Sci.:Part C 22 927-937 (1969), P Dole et al, Food Addit. and Contam. 2006, 23(2): 202-211

¹⁰⁴ TP Rusina, F Smedes, J Klanova, J. App. Polym. Sci. 116, 1803-1810 (2010)

4.6 Use of Aroclors in Paints and Coatings

Aroclors found limited use as an additive in paint and coating formulations during the 1930s to the early 1970s. As specialty components, they did not have widespread use, and formulations requiring Aroclors more frequently specified PCT-based Aroclors¹⁰⁵ rather than PCB-based Aroclors¹⁰⁶. Use of Aroclor PCBs in paints and other specialty coatings was typically limited to demanding industrial applications requiring the unique physical and chemical properties of PCBs, including for hot melt coatings,¹⁰⁷ marine paints,¹⁰⁸ water and weather resistance,¹⁰⁹ as a flame retardant,¹¹⁰ chemical resistance,¹¹¹ and abrasion resistance¹¹². Although formulations suggest Aroclor PCBs may be present from roughly 1 to 9% in the formulated commercial product, the actual concentrations effectively increase due to loss of solvent, resulting in concentrations in the range of approximately 2% to approximately 9% on a dry weight basis¹¹³. Thus, to the extent that a PCB was used as a plasticizer, it will be present at readily detectable levels.

All PCB containing paint formulations found in the literature by Exponent¹¹⁴ were targeted for industrial use; Exponent found no examples of PCB containing paint formulations targeted towards general consumer use.

¹⁰⁵ See, for example, US Patents 3,655,607; 3,295,346; 3,804,669; 2,481,687; 3,941,904; 3,763,224; 3,471,312; 2,427,481; 1,974,801

¹⁰⁶ See, for example, US Patent 2,204,550; 2,421,001; 2,579,610; 2,679,569; 2,720,496; 3,284,216; 3,811,904; Martens, CR, Technology of Paints, Varnishes and Lacquers, Reinhold Book Corporation, NY, NY 1968; Myers, RR, Long, JS, Film Forming Compositions, Vol 1, Chlorinated Rubber, Marcel Dekker Inc., NY, NY 1967

¹⁰⁷ US Patent 2,421,001

¹⁰⁸ US Patent 2,579,610

¹⁰⁹ US Patent 2,720,496

¹¹⁰ US Patents 3,284,216

¹¹¹ Martens, CR, Technology of Paints, Varnishes and Lacquers, Reinhold Book Corporation, NY, NY 1968

¹¹² US Patent 2,421,001

¹¹³ Exponent found one example of a temporary and removable wax-like coating using PCBs for metallic equipment where the PCB concentration was near 26%. This was not a paint, but rather a protective coating for transporting metallic machinery. US Patent: 2,421,001

¹¹⁴ A targeted literature and patent search was performed using Proquest dialog databases, as well as multiple general searches through trade and scientific journals of the time period 1930-1975. Keywords included Aroclor PCB, polychlorinated biphenyl, Arochlor, with conditionals including paint, coating, chemical, water, resistance, and fire.

4.7 By-product PCBs

The first commercial PCBs were produced by the Swann Chemical Company in 1929 through a process of heating biphenyls in the presence of chlorine gas and a metal catalyst. No known natural sources of PCBs exist,¹¹⁵ but many processes are known to produce PCBs as by-products of their production or degradation products of the materials. These by-products are also known as unintentionally produced PCBs. Of the 209 PCB congeners, well over half are known to be produced as by-products of existing chemical processes.¹¹⁶ The majority of these by-product PCB congeners can be found in some concentration in Aroclor formulations, although some congeners, such as PCB 11, are only generated from and present in by-product sources. Many processes exist that produce unintentional PCBs, some of which can produce PCB concentrations up to 2,000 PPM^{117,118}. Some of the process that produce the most by-product PCBs are described in greater detail below.

These production processes have been in existence for decades, and are not limited to production in the United States. Dates when some of the major by-product PCB producing processes were first discovered and implemented on a commercial scale are shown below in Table 5

¹¹⁵ Hu D, Martinez A, Hornbuckle KC; 'Discover of non-aroclor PCB (3,3'-dichlorophenyl) in Chicago air, Environ Sci & tech, Vol 42:21 (2008)

¹¹⁶ Deposition of Lisa Rodenburg, dated February 7, 2018, pp. 93-94

¹¹⁷ Study from the Japanese Ministry of Economy and Trade (METI) "Regarding organic pigments that contain PCB by-products at concentrations greater than 50 ppm", May 10, 2013

¹¹⁸ Polychlorinated Biphenyls in Consumer Products, State of Washington, 2016

Table 5. Dates of initial production and worldwide locations of various by-product PCB production processes

Chemical Process	First Discovered, Location (Company)	First commercialized, Location (Company)
TiO₂ production		
Chloride Process	ca. 1941, USA (DuPont) ¹¹⁹	ca. 1951, USA (DuPont) ¹¹⁹
Silicone Production		
Direct synthesis of chlorophenylsilane	ca. 1941, Germany and 1945, USA (General Electric) ¹²⁰	Likely in mid to late 1940s
Dichlorobenzoyl peroxide as crosslinker	ca. 1953, USA (Dow Corning) ¹²¹	Likely in mid to late 1950s
Organic Pigment Production		
Diarylide azopigments	ca. 1911 Germany (Griesheim-Elektron) ¹²²	ca. 1936 Germany ¹²²
Copper phthalocyanines	ca. 1935-1950 ¹²³	ca. 1935-1950 ¹²³
Internal Combustion Engine		
Various	Mid to late 1800s	Mid to late 1800s

¹¹⁹ DuPont began work on manufacturing process for TiO₂ using the chloride process in 1941, per Ghemawat, The Journal of Industrial Economics, 33(2), 1984, p. 154

¹²⁰ Direct synthesis of phenylchlorosilanes was independently described by researchers in Germany (1941) and the United States (1945), per Roesch et al., Silicone Compounds, Organic, Ullmann's Encyclopedia of Industrial Chemistry, 2012, p. 640; also described in US Patent 2,380,995

¹²¹ Dichlorobenzoyl peroxide was first described as a crosslinker in silicones in US Patent 2,723,966 (Assignee Dow Corning). This was followed in 1955 by US Patent 2,838,472 (assignee General Electric).

¹²² The first patent was filed as early as 1911, however the process did not gain industrial significance until the 1930s, Herbst and Hunger, Industrial Organic Pigments; Production, Properties, Applications, 3rd ed, Wiley VCH Weinheim, 2004

¹²³ The first process for preparation of phthalocyanine pigments from a phthalic anhydride was patented in 1935 by Imperial Chemical Industries of Great Britain (Lobbert, Phthalocyanines, in Ullmann's Encyclopedia of Industrial Chemistry, Volume 27, 2012, p. 191), however the use of chlorinated solvents is not specified. By 1950 the use of chlorinated solvents such as trichlorobenzene in this process is well known in the US (US Patent 2,673,854)

4.7.1 Organic Pigment Production

Pigments are chemical compounds that are used to add color to materials such as printing inks, paints, and plastics.¹²⁴ They are used as solid particles, making them distinct from dyes, which are solutions of dissolved coloring compounds (e.g., typical food colorings). Organic pigments in particular are derived from carbon-based compounds and are typically divided into categories based on their chemical structures. In 1999, the annual global organic pigments market was estimated to be 250,000 tons, with North America accounting for approximately 32% of production.¹²⁵ Two important classes of organic pigments are azopigments and phthalocyanines, which account for approximately 50%¹¹⁵ and 25%¹²⁶ of the pigment market, respectively. In particular, this section will focus on two subclasses of organic pigments which are associated with the production of by-product PCBs: (1) diarylide azopigments (nominally yellow or orange), and (2) copper phthalocyanines (nominally blue or green). Other classes of organic pigments such as monoazo pigments may also be associated with by-product PCB production,^{127,128} are used much less frequently compared to diarylide azopigments and phthalocyanines.

4.7.2 Diarylide Azopigments

Diarylide azopigments are symmetric organic molecules having general structures such as those shown in Figure 1. They are commonly used in the production of printing inks and, to a lesser extent, in the plastics industry.¹²⁴ Examples of industrially important diarylide pigments include Yellow 12, Yellow 13, Yellow 14, Yellow 17, Yellow 55, Yellow 81, Yellow 83, Orange 16, and Orange 17.^{7,127} The general structures of these nominally yellow and orange pigments are shown in Figures 1(a) and 1(b), respectively.

¹²⁴ Hunger and Herbst, Pigments, Organic, in Ullmann's Encyclopedia of Industrial Chemistry, Volume 27, 2012, p. 380.

¹²⁵ Bamfield, The restructuring of the colorant manufacturing industry, Rev. Prog. Color., 31, 2001, p. 6.

¹²⁶ Löbber, Phthalocyanines, in Ullmann's Encyclopedia of Industrial Chemistry, Volume 27, 2012, p. 203.

¹²⁷ Hu and Hornbuckle, Inadvertent Polychlorinated Biphenyls in Commercial Paint Pigments, Environ. Sci. Technol., 2010, 44, p. 2825

¹²⁸ Anezaki and Nakano, Journal of Hazardous Materials, 287, (2015), 111-117

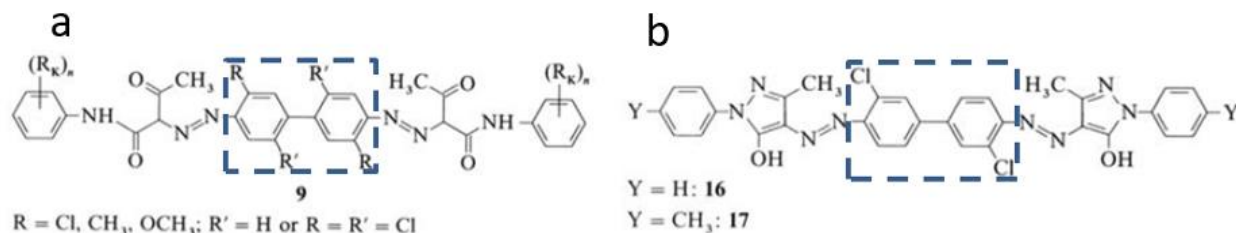


Figure 6. General structures of diarylide azopigments.⁷ A dashed box highlights the structure of PCB-11 or PCB-52 (depending on R and R' groups) in panel (a) and PCB-11 in panel (b).

Diarylide azopigments are synthesized from either 3,3'-dichlorobenzidine (for 2 chlorine atoms on the central biphenyl group) or 2,2',5,5'-tetrachlorobenzidine (for 4 chlorine atoms on the central biphenyl group) which is then reacted with two equivalents of an acetoacetic arylide.⁷ The resulting structure and color of the pigment are dependent on the choice of reactants. The choice of benzidine reactant may also influence the by-product PCBs which can form. For example, PCB 11 (3,3'-dichlorobiphenyl) may be formed when 3,3'-dichlorobenzidine is used,¹²⁹ and PCB 52 (2,2',5,5'-tetrachlorobiphenyl) may be formed when 2,2',5,5'-tetrachlorobenzidine is used.¹²⁷ However, other by-product PCBs have also been reported, as discussed below.

Anezaki and Nakano present a survey of PCB congeners in paint pigments, including results for many diarylide pigments.¹²⁷ For example, they found PCBs in samples of Yellow 12, Yellow 13, Yellow 14, Yellow 17, Yellow 55, Yellow 81, Yellow 83, Yellow 152, Orange 13, and Orange 16 from various manufacturers. As expected based on the chemistry discussed above, the primary PCB congener present in diarylide pigments was PCB 11 for those synthesized with 3,3'-dichlorobenzidine, and was PCB 52 for Yellow 81 which is synthesized with 2,2',5,5'-tetrachlorobenzidine. Other commonly detected PCB congeners included PCB 35 and 77. The total PCB concentrations ranged from 0.0070 to 740 mg/kg.

Scientific literature also provides indirect evidence of PCB production associated with the synthesis of diarylide azopigments. For example, Litten and coworkers reported results of

¹²⁹ King et al. "Tracing the source of 3, 3'-dichlorobiphenyl found in samples collected in and around Halifax Harbour, Marine Pollution Bulletin 44 (2002) 590-596

wastewater sampling from a pigment plant discharging into New York Harbor.¹³⁰ They found PCB 11, 35, 77, and 126 at approximate concentrations of 3600, 380, 190, and 1.6 ng/L, respectively. Additionally, Hu and Hornbuckle reported finding numerous PCB congeners in azo-based paint pigments including PCB 11 and 52, but cannot directly link their results to diarylide pigments due to the proprietary formulations used by paint manufacturers.¹²⁷ Similarly, Stone has reported PCB concentrations in many consumer products and found that PCB-11 concentrations were typically highest in products containing yellow pigments (labels, packaging, yellow colorant, and yellow spray paint), but the exact pigment types were not reported.¹³¹

4.7.3 Copper Phthalocyanines

Phthalocyanine pigments are organo-metallic complexes (i.e., are organic molecules which are coordinated with metal ions). The most industrially significant phthalocyanines are copper phthalocyanine (Figure 2, left) and derivatives thereof (e.g., perchlorinated copper phthalocyanine shown in Figure 2, right). These compounds have been produced industrially in the US since the late 1930's.¹²⁶ As of 1996, there were at least 27 manufacturers of phthalocyanine blue worldwide.¹²⁵ They are commonly used blue (Figure 2, left) and green (Figure 2, right) pigments for the production of printing inks and, to a lesser extent, in the paint and plastics industries.¹²⁶

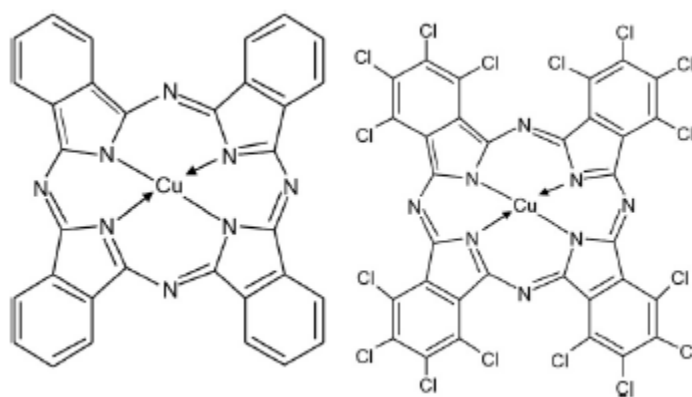


Figure 7. Chemical structures of copper phthalocyanine, a blue pigment (left) and perchlorinated copper phthalocyanine, a green pigment (right).

¹³⁰ Litten S, Fowler B, Luszniak D, 'Identification of a novel PCB source through analysis of 209 PCB congeners by US EPA modified method 1668, Chemosphere 46 (2002) 1457-1459

¹³¹ State of Washington Reports, Stone 2014 and Stone 2016

Copper phthalocyanine is synthesized on an industrial scale by two routes: (1) from phthalodinitrile and a copper source, or (2) from phthalic anhydride, urea, and a copper source.¹²⁶ The latter process is the most commonly used, and can lead to formation of PCBs when chlorinated solvents such as trichlorobenzene are used.¹³² The structure of the chlorobenzene used may determine which by-product PCBs can form.¹³² After initial formation of PCB congeners, the subsequent chlorination process to form the green pigment can produce the perchlorinated congener PCB 209.^{132,133} Other by-product PCBs have also been reported, as discussed below.

Scientific literature provides evidence of PCBs being formed during synthesis of copper phthalocyanine pigments. For example, in studies of copper phthalocyanine pigments by Uyeta and coworkers¹³³ and Buchta and coworkers¹³⁴, total PCB concentrations up to 243 ppm were detected, primarily composed of congeners with 5-6 chlorines which were hypothesized to have been created during pigment production with trichlorobenzene. Samples synthesized without chlorinated solvents, such as trichlorobenzene, contained no PCBs, and the chlorinated solvents themselves did not contain PCBs prior to phthalocyanine synthesis. Hu and Hornbuckle tested 6 commercial copper phthalocyanine paint pigments and found total PCB concentrations of approximately 2-198 ng/g.¹²⁷ They found congeners containing 1 to 10 chlorines, where phthalocyanine green pigments tended to have higher concentrations of congeners with higher chlorine content compared to phthalocyanine blue pigments. Anezaki and Nakano tested 13 phthalocyanine pigments, and PCBs were detected in 9 samples of phthalocyanine green. The total PCB concentrations ranged from 0.011 to 2.5 mg/kg, and the highest concentrations of congeners were often the highly chlorinated PCB 206, 207, 208, and 209.

¹³² Vorkamp K, "An overlooked environmental issue? A review of the inadvertent formation of PCB-11 and other PCB congeners and their occurrence in consumer products and in the environment, *Sci Total Environ* 541 (2016) 1463-1476

¹³³ Uyeta et al., Polychlorinated biphenyls in the phthalocyanine pigments, *Bulletin of Environmental Contamination & Toxicology*, 16(4), 1976, pp. 417-421.

¹³⁴ Buchta et al., Determination of polychlorinated biphenyls in copper phthalocyanine pigments, *Journal of Chromatography*, 325, 1985, pp. 456-461.

4.7.4 Titanium Dioxide Production

Titanium dioxide (TiO_2) is an inorganic compound commonly used as a white pigment. It is used in many commercial products including paints, paper, ceramics, coated fabrics, and floor coverings,¹³⁵ and is the predominant white pigment used in the plastics industry.¹³⁶ It has many functional advantages, including being low cost, non-toxic, and chemically stable.¹³⁷ Industrial production of TiO_2 started in the 1920s,¹³⁷ and total production was estimated to be 4.5 million tons worldwide in 2014.¹³⁸ US domestic production of TiO_2 pigment was estimated to be 1.16 million tons in 2015.¹³⁵

TiO_2 is produced through two primary industrial pathways: the “sulfate process” and the “chloride process”.¹³⁷ As of 2014, approximately 40% of worldwide TiO_2 was produced through the sulfate process, and the remaining 60% was produced using the chloride process.¹³⁸ The chloride process involves an intermediate step where titanium tetrachloride (TiCl_4) is produced,¹³⁷ which can also produce by-product PCBs (as discussed below). The sulfate process does not use this intermediate step, and thus the chloride process will be the focus of the discussion presented herein.

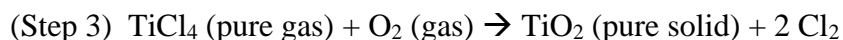
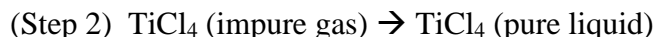
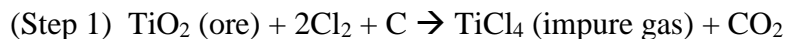
The chloride process was commercialized by DuPont in the early 1950s.¹³⁷ An example process description is given by Braun et al. and is summarized here.¹³⁷ The process begins with impure TiO_2 in the form of ore recovered from the earth via mining. In the first chemical processing step, the ore is treated with chlorine (Cl_2) and carbon (C) to produce a mixture of TiCl_4 and CO_2 gases. In the second step, the TiCl_4 is purified through distillation to recover a purified TiCl_4 liquid. In the last step, the purified TiCl_4 is reacted with oxygen (O_2) in the gas phase to produce solid TiO_2 and chlorine (Cl_2) gas. The TiO_2 is recovered as the desired product, and the chlorine is recycled for reuse. A simplified scheme of the processing steps and chemistry is summarized below:¹³⁷

¹³⁵ Mineral Commodity Summaries 2016, U.S. Geological Survey, pp. 176-177, available at <https://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf>

¹³⁶ Zweifel et al., *Plastics Additives Handbook*, 6th ed, p. 840

¹³⁷ Braun et al., *Progress in Organic Coatings*, 20, (1992), 105-138.

¹³⁸ Gazquez et al., *Materials Sciences and Applications*, 5, (2014), 441-458.



By-product PCBs can be created in the first processing step due to the reaction of chlorine (Cl_2) with carbon (C) during the TiCl_4 synthesis step.¹³⁹ In particular, highly chlorinated congeners such as PCB-209 may be produced.¹⁴⁰ For example, a TiO_2 colorant for paints was found to contain approximately 1.3 ppb PCB-209¹⁴¹ and a total PCB concentration of approximately 2.1 ppb.¹⁴² In a study of neat TiO_2 particles, Ctistis and coworkers reported finding PCB 101, 138, 153, and 180 at a total concentration of approximately 2600 ng/kg.¹³⁹ They hypothesized that the lower chlorinated congeners were formed from partial dechlorination of more highly chlorinated congeners during processing of the TiO_2 particles.

In addition to TiO_2 production, some TiCl_4 is also used for the production of titanium metal, and thus that process may also be associated with by-product PCB production,¹⁴¹ but limited data are available.

4.7.5 Silicone Production

Silicones, also known as polysiloxanes, are polymers with a backbone of repeating atoms of silicon (Si) bonded with oxygen (O) in the general form of $-\text{Si}-\text{O}-\text{Si}-\text{O}-$. Organic side groups such as phenyl rings can be attached to the silicon atoms via carbon (C)-Si bonds which allows for a wide variety of chemical and physical properties of the resulting silicone. In the United States, silicones have been commercially produced since the 1930's, originally by Corning Glass Works and the General Electric Corporation.¹⁴³ Silicone-based sealants have been available for

¹³⁹ Ctistis, Schon, Bakker, and Luthe, PCDDs, PCDFs, and PCBs co-occurrence in TiO_2 nanoparticles, *Environ Sci Pollut Res*, 2015.

¹⁴⁰ Panero, Boehme, and Munoz, Pollution Prevention and management Strategies for Polychlorinated Biphenyls in The New York/New Jersey Harbor, New York Academy of Sciences, February 2005.

¹⁴¹ Stone, Polychlorinated biphenyls (PCBs) in general consumer products. Department of Ecology, State of Washington, (Publication No. 14-04-035, June 2014), p. 20. Available at <https://fortress.wa.gov/ecy/publications/publications/1404035.pdf>

¹⁴² Stone, Polychlorinated Biphenyls in Consumer Products, Department of Ecology, State of Washington, (Publication No. 16-04-014, November 2016), p. 32.

¹⁴³ Roesch et al., Silicon Compounds, Organic, Ullmann's Encyclopedia of Industrial Chemistry, 2012, p. 638.

use in the construction industry since around 1960.¹⁴⁴ In general, silicones of today are noted for their high thermal stability, electrical insulating properties, and biocompatibility,¹⁴⁵ But required nearly two decades of research between 1950-1970 to refine into their higher-performing properties. When silicones exist as linear polymers, they are typically liquids at ambient conditions (e.g., silicone oil). However, when chemical crosslinking is performed, they take on a rubber-like solid form known as silicone elastomers. In 1999, the global consumption of silicone elastomers was estimated to be 170,000 tons.¹⁴⁵

There are two chemical components used in the production of some silicones which are associated with incidental PCB production: chlorophenylsilanes¹²⁷ (a family of compounds which are raw materials used for the production of phenyl silicones) and dichlorobenzoyl peroxide¹⁴⁶ (a cross-linking agent used to form silicone elastomers).

4.7.6 Chlorophenylsilanes

Depending on the desired silicone product, various raw materials and production processes may be used in their synthesis. For example, chlorophenylsilanes are used when phenyl organic side groups are desired, and are commonly used in the production of silicone-based adhesives and sealants.¹⁴⁷ Chlorophenylsilanes are a family of compounds, some of which are shown in Figure 1 below, and may contain between one and three phenyl rings and between one and three chlorine atoms all attached to a central silicon atom.

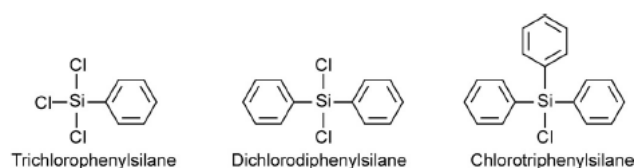


Figure 8. Chemical structures of some chlorophenylsilanes¹⁴⁶

¹⁴⁴ Lacasse, Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, Special Technical Publication Series No. 1271, October 1997.

¹⁴⁵ Jerschow, Silicone Elastomers, Rapra Review Reports, Report 137, 2001, p. 5.

¹⁴⁶ Perdih and Jan, Formation of PCBs in Silicones, 1994.

¹⁴⁷ Anezaki and Nakano, Journal of Hazardous Materials, 287, (2015), 111-117

Chlorophenylsilanes are produced through reaction of chlorobenzene with silicon, catalyzed by a metal such as silver.¹⁴³ However, undesired products including mono- and di-chlorinated PCBs (e.g., PCB-1, 2, 3, 4, 6, 8, 11, 13, and 15) may also form from the reaction of two chlorobenzene molecules in a process known as dimerization¹⁴⁷. A simplified schematic showing the synthesis of chlorophenylsilanes and the likely PCB products is shown in Figure 2.

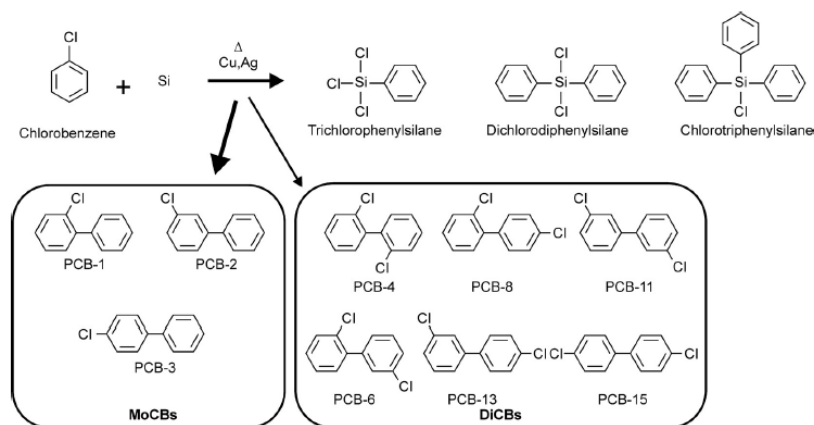


Figure 9. Simplified schematic showing the synthesis of chlorophenylsilanes and the possible PCB by-products.¹⁴⁷

Scientific literature demonstrates that PCBs can be present in chlorophenylsilanes and silicones synthesized from them. For example, Anezaki and Nakano reported PCB concentrations up to 1,500 mg/kg in pure chlorophenylsilanes and up to 40 mg/kg in silicone adhesives formulated from them.¹⁴⁷ In all cases, mono-chlorinated PCBs were the majority PCB congeners present, with di-chlorinated congeners being the next most significant contributions. In a prior study of silicone adhesives, they found 40-61 mg/kg total PCB content in two products, with over half being mono-chlorinated PCB 2 and 3.¹⁴⁸

4.7.7 Dichlorobenzoyl Peroxide

As described earlier, crosslinking agents are used to form silicone elastomers, where the intermolecular bonds provide their desirable mechanical properties (a similar process to vulcanization of rubber, which uses sulfur to create intermolecular bonds). There are two

¹⁴⁸ Anezaki and Nakano, *Organohalogen Compounds*, 75, (2013), pp. 517-520.

common mechanisms used to form silicone elastomers, often referred to as “curing”: addition curing and peroxide curing.¹⁴⁹ Dichlorobenzoyl peroxide (also known as “2,4-dichlorodibenzoylperoxide” or “bis(2,4-dichlorobenzoyl) peroxide”) can be used in high temperature crosslinking of silicones via peroxide curing.^{146,149} The chemical structure of dichlorobenzoyl peroxide is shown in Figure 3.

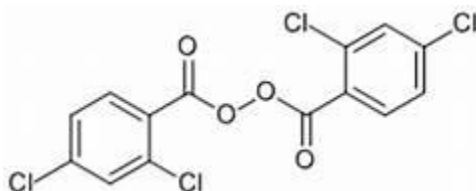


Figure 10. Chemical structure of dichlorobenzoyl peroxide.

When exposed to high temperatures such as those used in the crosslinking reaction, dichlorobenzoyl peroxide molecules can react with each other to form by-product PCBs. Scientific literature demonstrates PCBs can be present in silicone elastomers, often investigated in silicone tubing applications.¹⁵⁰ For example, Perdih and Jan reported finding over 20 PCB congeners in samples of silicone tubing, with a total concentration of 9.76 mg/kg.¹⁴⁶ Only congeners with five or fewer chlorine atoms were found, and only the di-chlorinated PCBs 4 and 8 were found at concentrations above 1 mg/kg.

4.7.8 Combustion Processes

Combustion is the oxidation of chemical compounds which releases heat and chemical products including gases, ash, and soot. PCBs may be formed and released due to incomplete combustion in processes involving organic material and a chlorine source.¹⁵¹ A possible formation mechanism was proposed by Ballschmiter and coworkers and involves dimerization of chlorobenzenes formed during combustion via a radical reaction, but other mechanisms are also

¹⁴⁹ Jerschow, *Silicone Elastomers*, Rapra Review Reports, Report 137, 2001, pp. 48-49.

¹⁵⁰ Leidos, Technical Memorandum: Potential for PCB Contamination from Sampling Equipment Tubing Materials, November 23, 2016, pp. 1-6.

¹⁵¹ Ishikawa et al., PCB decomposition and formation in thermal treatment plant equipment, *Chemosphere*, 67, 2007, pp. 1383-1393

possible.¹⁵² The following section discusses selected scientific literature related to combustion processes as sources of PCBs in the environment, and is focused on vehicle engines and incinerators.

Scientific literature demonstrates that vehicle engines can be sources of PCBs in the environment. One of the earliest studies which connected vehicles with PCB emissions was by Granier and Chevreuil, which demonstrated that PCB 18, 28, 52, 60, 101, 138, 153, and 180 were detected in vehicle emissions collected via air sampling in a traffic tunnel in France in 1990.¹⁵³ Later, Broz and coworkers demonstrated that a gasoline engine could produce PCBs containing 3-9 chlorines, with a total PCB emission concentration of approximately 89-205 pmol/m³ in the exhaust gases, depending on operating conditions.¹⁵⁴ Additionally, Cooper and Peterson demonstrated that diesel engine exhaust can contain PCB 28, 52, 101, 118, 138, 153, and 180.¹⁵⁵ Based on their measurements, they estimated that ferry boat traffic in the Skagerak-Kattegatt-Oresund region near Norway produced approximately 1 kg of PCBs per year as of 1996. A study of modern diesel engines found that PCB-77, 105, 114, 118, 123, 156/157, 167, 189, and 209 were produced in detectible quantities, where each concentration was up to nearly 500 pg/L of fuel consumed when no catalytic emissions control device was used.¹⁵⁶ Emissions were significantly reduced when a catalytic emissions control device was used, were no congener was detected above 3 pg/L in some operational conditions.

There is also consensus that incinerators can be sources of PCBs. In some studies, the creation of highly chlorinated PCB congeners was found, such as the highly chlorinated PCB 205 by Ballschmiter and coworkers, and PCB 194, 206, and 209 by Ishikawa and coworkers.¹⁵¹ In the latter study, the highly chlorinated PCB congeners were hypothesized to have been created due

¹⁵² Ballschmiter, Niemczyk, Schaefer, and Zoller, Isomer-specific identification of polychlorinated benzenes (PCBz) and -biphenyls (PCB) in effluents of Municipal waste incineration, *Fresenius Z Anal Chem*, 328, 1987, pp. 583-587.

¹⁵³ Granier and Chevreuil, Automobile traffic: A source of PCBs to the atmosphere, *Chemosphere*, 23(6), 1991, pp. 785-788.

¹⁵⁴ Broz, et al., The effect of oils on PAH, PCDD, PCDF, and PCB emissions from a spark engine fueled with leaded gasoline, *Chemosphere*, 41, 2000, pp. 1905-1911.

¹⁵⁵ Cooper and Peterson, Hydrocarbon, PAH and PCB emissions from ferries: A case study in the Skagerak-Kattegatt-Oresund region, *Atmospheric Environment*, 30(14), 1996, pp. 2463-2473.

¹⁵⁶ Laroo et al., Emissions of PCDD/Fs, PCBs, and PAHs from a Modern Diesel Engine Equipped with Catalyzed Emission Control Systems, *Environmental Science & Technology*, 45, 2011, pp. 6420-6428 and supporting information.

to high chlorine content in the feed material combined with the catalytic chlorination effects of iron and/or copper. A study by Ikonomou and coworkers examined municipal waste incinerators in Korea and found that the general profiles of PCBs in the flue gases suggested that, in some cases, PCBs from the feedstock material were being liberated, while new PCBs were being created in other cases, depending on operating conditions.¹⁵⁷

4.8 The City of Spokane

In the course of my analysis in this matter I reviewed reports and consolidated results showing PCB testing results at various locations in and surrounding the Spokane River and the city of Spokane,¹⁵⁸ as well as reports detailing numerous industrial and consumer products found in and around Spokane that contain by-product PCBs.¹⁵⁹ The majority of these reports focus on testing and analysis of waterways and soil, which is outside my scope, but I will address statements and results that focus on building materials that incorporated PCB plasticizers, such as caulk. Additionally I address reports on by-product PCBs.

PCBs are known to be the by-product of other processes, including manufacturing and combustion, as outlined earlier. These PCBs are not from Aroclors. The State of Washington and City of Spokane attempted to estimate the amount of PCBs from by-product sources by testing products manufactured well after PCBs were withdrawn from the market for use in formulations. The products included many consumer products including but not limited to toothpaste, soap, motor oil, and road paint. 39 of the 41 samples contained PCB congeners at levels up to 2.51 ppm.

As part of a larger attempt to estimate the total amount of PCBs in various sources, including building materials like caulks, in the City of Spokane, the state of Washington and the City of

¹⁵⁷ Ikonomou et al., PCB levels and congener patterns from Korean municipal waste incinerator stack emissions, *Chemosphere*, 49, 2002, pp. 205-216.

¹⁵⁸ For example: 2016 Comprehensive Plan to Reduce Polychlorinated Biphenyls (PCBs) in the Spokane River, Report by LimnoTech, November 29, 2016; Spokane River Urban Waters Source Investigation and Data Analysis Progress Report (2009-2011) Department of Ecology, State of Washington, September 2012, Publication No. 12-04-025; Spokane River PCB Source Assessment 2003-2007, Department of Ecology, State of Washington, April 2011, publication number 11-03-013.

¹⁵⁹ PCBs in Municipal Products, Ecology Municipal Stormwater Grants of the Regional or Statewide Significance - revised, Grant No. G1400545, July 21, 2015.

Spokane applied information from a Toronto-based study.^{160,161} This approach suffers from many deficiencies, including a lack of basis in Spokane. For example, the type, age, quality and function of construction in the Toronto study has not been correlated to Spokane; the only correlation described in the report is one that scales the PCB amount estimates by the population of the city. This is one reason why the Spokane estimates have a high level of uncertainty.¹⁶¹ Furthermore, no building materials were sampled to determine the presence of PCBs. PCB plasticizers were used in specific building materials when Aroclors were commercially available, but their level of use in Spokane is unknown. Importantly, due to their chemical properties, to the extent they were used, the Aroclors generally remained in the formulated materials. Currently, however, all of the formulated materials, and especially caulks, are well past their expected lifetimes, and therefore should have already been replaced. Thus, there is no validation of the use of the population-scaling approach for quantifying actual PCB amounts in Spokane.

¹⁶⁰ Diamond M, Melymick L, Csiszar S, Robson M, Estimation of PCBS Stocks, Emissions, and Urbane Fate: Will our Policies Reduce Concentrations and Exposures, Environ. Sci. Technol. 2010, 44, 2777-2783

¹⁶¹ 2016 Comprehensive Plan to Reduce Polychlorinated Biphenyls (PCBs) in the Spokane River, Report by LinnoTech, November 29, 2016

5 Response to Plaintiff's Experts

I have reviewed the expert report of Dr. Jack Matson dated August 6, 2019 and the combined report of Drs. Markowitz and Rosner dated October 11, 2019. The rebuttal below is in the context of my scope of work as a material scientist, formulator and product development engineer. I address issues related to chemical functionality and performance, technical supply chain communications, and the state of the art in polymeric materials formulation during the time frame in which Aroclors were available for use as plasticizers.

I have also reviewed the reports of Dr. Lisa Rodenburg and Mr. Kevin Coghlan. Both have made estimates of the presence of Aroclor PCBs in Spokane, including from plasticizer sources. Dr. Rodenburg's method of assignment has a high potential for bias because all of the PCBs in the samples are assumed to be Aroclors, even with poor correlation to congener content and proportions. Although Mr. Coghlan indicates that his estimates favored non-Monsanto PCB assignment, he does not consider any Spokane-specific data other than from Dr. Rodenburg's analysis, and a population-based correlation to non-Spokane data. Furthermore, his analysis appears to ignore or discount uncertainty associated with the information that is the basis for his analysis, including the assumed presence of PCB-plasticized materials.

5.1 Response to Dr. Jack Matson

I have reviewed Dr. Matson's report dated August 6, 2019. A full response to Dr. Matson's report is outside my scope, but I will focus on topics specifically relevant to my assignment, background and expertise. Within his report, Dr. Matson discusses topics such as formulation, the mindset of a formulator, and considerations employed by formulators when designing and creating new materials. I note that, unlike myself, Dr. Matson has never been a formulator or material developer.

I disagree with many of Dr. Matson's statements because he selects specific quotes and documents and presents them without appropriate scientific or industrial context, especially as they relate to the scientific state of the art at the relevant times, Monsanto's role in the supply chain, and the effects of formulation on component performance. For example, Dr. Matson

repeatedly asserts that Monsanto was responsible for end product properties and use. However, Monsanto was a raw material supplier, not a formulator, and would not know the end formulations of the compounds using its products, or the testing and performance that would be relevant to the end product applications. Monsanto's customers were scientifically sophisticated and they, not Monsanto, were responsible for their own product compositions, testing and performance.

As described in my report above and in my responses below, Monsanto appropriately communicated scientific concepts to sophisticated customers about a raw material with unique properties. Monsanto's customers were scientifically sophisticated, with sufficient information to consider which, if any, of Monsanto's plasticizers might be appropriate for an application, and to appropriately assess the formulated compounds these customers created and sold.

5.1.1 Monsanto's customers understood the volatility, vapor pressure and migration aspects of PCBs

Dr. Matson's report discusses the ability of Aroclor PCBs to volatilize from formulated products, though his analysis appears to lack understanding of Monsanto's role in the supply chain, chemical and physical principals related to formulation, and the relevance of certain statements or articles to standard conditions. His statements confound the scientific knowledge of the time and provide misleading statements that are not based in fact, or are contradictory to his testimony statements. For example, Dr. Matson affirmed in deposition that PCBs have a "*very low or insignificant volatility*",¹⁶² yet throughout his report Dr. Matson asserts that Monsanto mislead customers in the low vapor pressure values of Aroclors.

When Dr. Matson states in his report, "*Monsanto created and sustained the PCB market for these applications without providing sufficient information to its customers that PCBs would continue to migrate out of these applications and into the environment*",¹⁶³ he appears to have ignored the level of fundamental, practical and industry-specific knowledge held by Monsanto's customers and the many examples of relevant technical information provided by Monsanto

¹⁶² Deposition of Jack Matson, September 9, 2016, pp. 308-309

¹⁶³ Matson report, p. 29

directly and in literature by Monsanto and others. As I have outlined previously, Monsanto provided measurements of vapor pressure and other fundamental properties of Aroclors that would indicate to any formulator that PCBs exhibit phase equilibria and diffusion behavior, and this corresponds to a finite ability to volatilize and migrate by diffusion, depending on the conditions. Indeed, he refers to examples of this information in his report.¹⁶⁴ As I have repeatedly explained, volatility data regarding Aroclors was available in the public literature for nearly the entire time PCBs were available for sale in the United States.

5.1.2 **Monsanto's data regarding Aroclor volatility was not misleading**

Dr. Matson's assertion that Monsanto's data on volatilization "*was misleading because the omission of low temperature volatilization data did not allow for customers to evaluate harmful impacts to the public or the environment from open use products*"¹⁶⁵ is unsubstantiated, discounts the knowledge of formulators, and is a misrepresentation of the scientific capabilities of the time. As described above in Section 4.3, scientists and engineers trained in the time period PCBs were available were well versed in various aspects of vapor pressure, including extrapolating from volatilization test data to possible vapor pressure data at lower temperatures.¹⁶⁶ Low temperature measurements of materials with very low vapor pressures, such as the Aroclors, are difficult, and results can vary between laboratories, operators and test methods. The mixture of congeners with different molecular weights and different individual vapor pressures additionally convolutes the test method and results. Monsanto's presentation of raw data to its scientifically sophisticated formulators was not misleading.

Dr. Matson goes on to state that Monsanto misled customers regarding vapor pressure due to his specific extrapolation of raw data compared to Monsanto's. He states "In the table of *"Approximate Vapor Pressures," the vapor pressure of Aroclor 1254 was reported as 0.00006 mmHg (6x10-5mmHg) at 100°F (37.8°C). This value was incorrectly and repeatedly*

¹⁶⁴ Matson report, pp. 4 & 34

¹⁶⁵ Matson report, p. 5

¹⁶⁶ Data extrapolations are performed according to specific equations, notably the Clausius-Clapeyron equation. While this and other equations are known to provide generally good approximations, extrapolating outside of known data can be a significant source of error in a property estimation.

*underreported in Monsanto's technical bulletins, which leads to incorrect assumptions about PCB concentrations indoors at ambient temperatures".*¹⁶⁷ As discussed above in my report, vapor pressures are difficult to measure and the values provided by Monsanto have been validated in recent years. Pure materials can be characterized by their vapor pressure, which is a measure of volatility, or conversion of the material to the gas phase, under specific conditions. Vapor pressure is related to the material's chemistry, size, and surrounding temperature. Indeed, for some materials, including Aroclors, vapor pressure is too low to be measured at room temperature; elevated temperature are required to obtain measurements that may be used to extrapolate estimated values for the pure material at a selected set of conditions. Often, this qualitative information is enough for a formulator to select a material for evaluation in their composition. Formulation-specific evaluation is important because interaction forces due to chemical attraction and physical limitations on mobility also impact volatility. Thus, a simplistic assessment of the vapor pressure of a pure material cannot be used to reliably the functional vapor pressure in a formulated compound.¹⁶⁸ A formulator would not singularly rely on quantitative vapor pressures estimated for very low volatility pure materials to understand the expected behavior of the particular formulations he or she were developing for an end use.

Monsanto provided information related to Aroclor PCBs including chemistry, handling, and properties such as vapor pressure, as well as comparative information for pure materials and non-commercial example formulation made with different plasticizers to its customers, the formulators. This chemical information provided Monsanto's technically trained customers with details that would inform their subsequent use and handling.⁴ Because of the basic mode of action of a plasticizer, all plasticizers have a vapor pressure, and Monsanto's data showed that Aroclor PCB plasticizers beneficially offered low vapor pressure along with desirable properties for modifying polymer formulations' performance.

The volatility of PCB plasticizers from formulated materials will depend on many factors that Monsanto cannot reliably know or control. Indeed, Dr. Matson references reflect this, despite his

¹⁶⁷ Matson report, p. 39 (TOWOLDMON0005563, 1960; DSW 352447, 12/1960; TOWOLDMON0024978, 10/31/1966)

¹⁶⁸ See section 4.3 for a more detailed discussion.

intent to suggest that formulators were unaware. For example, his report identifies various weight loss tests associated with end-use markets noting that, “The volatilization losses were determined not only by the plasticizer alone, but by the plasticizer resin combination and the thickness of the finished product (Reed, 1943; Craver, 1948; Boyer, 1949; Doolittle, 1954; MONS 080627, 1961; American Chemical Society, 1965; Mellan, 1961).”¹⁶⁹ Dr. Matson even references a federal specification,¹⁷⁰ which specifies that a formulated sealant must undergo weight loss measurements. All of this demonstrates the fact that formulations containing Aroclors were intended and expected to be tested according to application- specific requirements, once formulated by Monsanto’s customers, and that individual raw material properties cannot substitute for results for formulated materials.

5.1.3 PCB-containing paints were intended for specific industrial applications, not general consumer use.

Dr. Matson again uses development level testing, this time related to Lustrex Latex paints, to suggest that Monsanto promoted Aroclors for this use.¹⁷¹ In fact, Monsanto did not recommend PCBs for use in household paint. The testing performed was specific to the Lustrex of paint and cannot be used to determine how PCBs would behave in other host material combinations, such as, caulks, sealants or even paints with different formulations and constituents. The tests discussed were performed on heated surfaces or in rooms with limited ventilation and elevated temperatures, which were not realistic ambient conditions. Further, the chemical testing of the time measured all chlorine sources, and was not specific to PCBs. As a result, Monsanto did not actually know if they were detecting PCBs or other chlorine containing compounds during this testing

Monsanto did provide qualitative descriptions of Aroclor properties, especially as they might related to general categories of use, such as coating compositions. Indeed, Aroclors did provide many essential properties to certain industrial coatings. However, as noted above, Monsanto did not recommend Aroclor-based paints for consumer use. As described in the main body of this

¹⁶⁹ Matson report, (Appendix B, Pdf p. 94/149 –please note the pagination of Dr. Matson’s report is not consistent here, hence the usage of the pdf paging)

¹⁷⁰ Federal Specification TT-S-230A, Dated 2/3/1964

¹⁷¹ Matson report pp. 34-35 (MONS 061753, DSW 147758)

report, while numerous examples of specialized industrial paints and coating formulations have been identified, Exponent has not found any formulations in the literature or patents of the time that suggest PCBs were used in household paints.

5.1.4 **Formulators make independent technical decisions**

Dr. Matson has suggested that Monsanto's technical communications to potential customers and internal communications related to potential new markets demonstrate that Monsanto was making independent decisions about the composition and use of formulated products sold by its customers. This is not true. Monsanto provided reference and comparative information and customer-driven technical support related to its plasticizer products in a variety of forms, including tables of standardized data, technical brochures that included health and safety guidance, approvals with various regulations (e.g., various communications and formal documents confirm that Monsanto did not recommend Aroclor plasticizers for food contact applications), and other typical chemical information, including information about volatility and permanence of the pure plasticizers.^{172,10,11} Produced documents¹⁸ also provide numerous examples of feedback from Monsanto's customers and these customers were testing, comparing and deciding on commercial formulations. Aroclors were used in industrial applications requiring particular combinations of properties that were determined and assessed by Monsanto's customers in light of their particular applications.

Dr. Matson also asserts that Monsanto misled customers by stating incorrect vapor pressure measurements. These assertions are inconsistent with the scientific capabilities and sophistication of Monsanto's customers, as exemplified by information in Appendix D. Indeed, Dr. Matson affirmed under oath, that in matters related to Monsanto's communication regarding PCBs, "There's no way [he] can tell that the information provided ultimately would create a behavioral change".¹⁷³

¹⁷² For example: Plasticizer Blue Book – 1969 MONS077721, MONS080640 – Monsanto Plasticizers; MONS077728-MONS077730 The Plasticizer Blue Book

¹⁷³ Affidavit of Jack Matson, in the Town of Westport v Monsanto Company et al., dated 12/21/2016

5.1.5 There was no one-to-one substitute for Aroclor plasticizers

Dr. Matson goes on to discuss that there were suitable substitutes for Aroclors in nearly all products, and references Broadhurst¹⁷⁴ as his example. Dr. Matson fails to recognize that the Broadhurst paper is merely discussing chemical compatibilities within his 1972 paper and not discussing the functionality of the plasticizers. Broadhurst discusses chemical compatibility and physical characteristics such as density, dielectric strength, thermal conductivity, etc., but does not discuss any resulting composition properties such as plasticizer efficiency, elongation, strength, toughness, weatherability, etc. Dr. Matson is confusing compatibility with functionality. Plasticizer compatibility does not make a plasticizer functional for a particular end use, though lack of compatibility can eliminate a candidate plasticizer. This is one reason why discontinuation of a raw material can be disruptive for product manufacturers. In the case of materials with unique attributes, it is not unusual to stockpile a certain amount of material when notified of a pending change in order to mitigate the risk associated with finding a replacement. Multiple documents exist in which Monsanto customers state that they cannot find suitable alternatives to the Aroclor PCBs for their products.¹⁷⁵

5.2 Response to Dr. Gerald Markowitz and Dr. David Rosner

I have reviewed the report of Dr. Gerald Markowitz and Dr. David Rosner dated October 11, 2019. My response to their report will focus only on the areas where my expertise overlap with their report. Drs. Markowitz and Rosner generally refer to documentation and statements produced by Monsanto, which they use to conclude Monsanto's corporate behavior was inappropriate. While corporate behavior is outside my scope, scientific formulation and knowledge is in my scope. To the extent Drs. Markowitz and Rosner argue against Monsanto's behavior, for reasons I have explained above and throughout this report, their arguments do not account for appropriate issues and knowledge associated with supply chain, chemical and physical properties of these materials, and the level of scientific sophistication of Monsanto's customers.

¹⁷⁴ Broadhurst, M.G., *Enviro Health Persp.*, pp. 80-102, October (1972)

¹⁷⁵ For example, TOWOLDMON0053042, TOWOLDMON0054001, TOWOLDMON0054003

Appendix A

Curriculum Vitae of Maureen T.F. Reitman, Sc.D., P.E.



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Professional Profile

Dr. Reitman leverages her understanding of the fundamental principles of materials science and the technology of macromolecules to assess risk and performance for end users, distributors, manufacturers, product designers and raw material suppliers across a wide range of industries. Her expertise includes polymer and composite technology, mechanics of materials, adhesion science, fiber mechanics, history and technology of plastics, and material failure analysis. She is skilled in the development and use of testing tools and methods and has applied them to plastic, rubber, textile, metal, glass, ceramic, and composite materials and systems. She is experienced in major aspects of product development, including materials selection, formulation, scale-up, end-use testing, failure analysis, certification procedures and issues related to intellectual property.

Dr. Reitman has conducted research in the areas of medical plastics and devices including implants, diagnostic components, and transdermal drug delivery systems; plastic packaging and barrier materials; paints and coatings; plastic pipes; spray foam insulation; adhesives, sealants, and encapsulants; additive manufacturing / 3D printing; molding compounds; composite materials; high temperature resins; rubber gaskets and seals; nanoparticles; fibers and textiles; polymer chemical resistance; wire and cable insulation; connectors and splices; environmental effects on durability; and product aging. She has used her expertise to address problems and opportunities related to coatings, fibers, films, and extruded and molded products, and their use in the telecom, electronics, electrical, energy, transportation, construction, fire protection, medical, and consumer products markets. Dr. Reitman also assists clients with matters related to intellectual property, including support related to patent filings, technical due diligence, and technical aspects of trade secret, patent infringement, and patent validity disputes.

Dr. Reitman is active in technical and business advisory roles. She is a member of the Board of Directors of the Medical Plastics Division and the Failure Analysis and Prevention Special Interest Group of the Society of Plastics Engineers as well as an active member of two Underwriters Laboratories Standard Technical Panels, addressing Polymeric Materials (UL 94, UL 746, UL 1694) and Appliance Wiring (UL758). Additionally, Dr. Reitman has served on technical advisory boards for materials and manufacturing companies.

Prior to joining Exponent, Dr. Reitman worked for the 3M Company in both research and management roles. Her activities included technology identification, materials selection and qualification, product development, customer support, program management, acquisition integration, staff and organizational development, intellectual property analysis, and patent litigation support.

Academic Credentials & Professional Honors

Sc.D., Materials Science and Engineering, Massachusetts Institute of Technology (MIT), 1993

B.S., Materials Science and Engineering, Massachusetts Institute of Technology (MIT), 1990

Fellow of the Society of Plastics Engineers

National Academy of Engineering Frontiers of Engineering, 2009

Tau Beta Pi

Sigma Xi

John Wulff Award

Carl Loeb Fellowship

NCAA Postgraduate Scholarship

Malcolm G. Kispert Award

GTE Academic All-American

Licenses and Certifications

Professional Mechanical Engineer, Maryland, #46268

Professional Affiliations

American Association for the Advancement of Science (member)

American Association of Textile Chemists and Colorists — AATCC (senior member)

American Chemical Society (member)

ASTM International (member)

Society for the Advancement of Material and Process Engineering (member)

Society of Plastics Engineers (Fellow)

Professional Appointments

Underwriter's Laboratory Standards Technical Panel STP 746 (Polymeric Materials, includes UL94, UL 746 and UL1694)

Underwriter's Laboratory Standards Technical Panel STP 758 (Appliance Wires/ UL758)

Medical Plastics Division Board of Directors, Society of Plastics Engineers

Failure Analysis and Prevention Special Interest Group Board of Directors, Society of Plastics Engineers

Patents

Patent 6,311,524: Accelerated Method for Increasing the Photosensitivity of a Glassy Material, issued November 6, 2001.

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Comerford PJ, Vernon DV, Reitman, MTF. 3DP/AM revolution is also a legal revolution. (<http://www.manufacturing.net/articles/>) December 2013.

Comerford, PJ and Reitman, MTF. The 3DP/ AM revolution . *Today's Medical Developments* (cover story) (www.onlinetmd.com), October 2013.

Reitman, MTF, Moalli JE. Polymeric coatings for medical device. *Medical Device and Manufacturing Technology*, Touch Briefings 2006; pp. 28-30.

Selected Invited Presentations

Wade, RJ, Kiel J, Reitman M TF. Oxidative stability of polypropylene for biomedical applications. 257th American Chemical Society Meeting. Orlando April 2019.

Reitman MTF. Service Life and Practical Risk: Incorporating failure modes and predictive tools in product development. NIST/ UL Conference on Service Life Prediction of Polymeric Materials: Reaching New Heights. Boulder, CO March 2018.

Reitman MTF. Innovate from what you know: Tips and tricks for medical device development. Teel Medical Plastics Summit, Minneapolis MN, November 2017.

Reitman MTF. Characteristics and Stability of Implantable Polypropylene Fibers. Medical Plastics Minitec, Society of Plastics Engineers, Durham, NC, April 2016.

Reitman MTF. 3D Printing technology viewed from the inside: Recognizing opportunity and managing risk. Presenter and panelist, Product Liability Advisory Council Spring Meeting, Miami, FL, March 2016.

Reitman MTF. To Your Health: Polymers in Biology and Medicine. Medical Plastics Keynote. ANTEC 2015 Conference, Orlando, FL, March 2015.

Reitman MTF. Turning failure into success: tools, techniques and practical examples for product development engineer. ANTEC FAPSIG Tutorial, Las Vegas, NV, April 2014.

Reitman MTF. Materials science of surgical meshes: Polypropylene for soft tissue repair. AATCC International Conference, Materials Track-Medical Textiles, Ashville, NC, April 2014.

Reitman MTF. PEEK: A structure-property-performance overview for medical device designers. AAOS/Solvay Education Summit: Healthcare Industry Perspective to Support Innovation and Product Development in a Challenging Global Environment, New Orleans, LA, March 2014.

Reitman MTF. Assessment of proposed division by type for F2026 in light of material, manufacturing and testing variability. ASTM F04 Committee meeting, Jacksonville, FL, November 2013.

Reitman MTF. Materials science of surgical meshes: Polypropylene for soft tissue repair. American Urogynecology Society (AUGS) 34th Annual Scientific Meeting, Mesh Special Interest Group, Las Vegas, NV October 16, 2013.

Reitman MTF. Structure-property overview of medical polymers. 4th China International Medical Device Regulatory Forum (CIMDR), Xi'an, China, September 2013.

Reitman MTF. Failure analysis of polymeric materials in medical applications: Lessons for successful material selection. Polymers and Plastics in Medical Devices San Francisco, CA, June 2013.

Reitman MTF. Failure analysis tools. Workshop on Future Needs for Service Life Prediction of Polymeric Materials. NIST and Underwriters Laboratories, Gaithersburg, MD, October 2012.

Hoffman J, MacLean S, Ralston B, Reitman M, Ledwith P. Fractography of unfilled thermoplastic materials experiencing common mechanical failure modes. Materials Science & Technology 2012 Conference, Pittsburgh PA, October 2012.

Hoffman J, Reitman M, Ledwith P. Microscopic characterization of CPVC failure. Materials Science & Technology 2012 Conference, Pittsburgh PA, October 2012.

Reitman MTF. Polymer material properties for next generation medical devices. Invited Speaker: MedTech Polymers, UBM Canon, Chicago, IL, September 2012.

Reitman MTF. Polymers for medical applications. Fundamentals and Fellows Forum, ANTEC 2012, Orlando FL, April 2012.

Reitman MTF. Plastic and composite product failures. Invited lecture in Failure Analysis of Emerging Technologies. Stanford University Department of Materials Science and Engineering, Menlo Park, CA October 2009.

Reitman MTF. Factors for success: Plastics in injection molded medical devices. Part of Injection Molding Works for Medical Design, Design News Webcast, October 2008.

Reitman MTF. Plastic and composite product failures. Keynote Speaker: Third International Conference on Engineering Failure Analysis (ICEFA III), Elsevier, Sitges Spain, July 2008.

Reitman MTF. Multiphase materials for medical device applications, an overview. Medical Device and Manufacturing (MDM), Canon Communications, various locations, Jan-June 2008.

Reitman MTF. Nanotechnology and plastics for medical devices. Capitalizing on Nanoplastics, Intertek PIRA San Antonio TX, February 2008.

Reitman MTF. Nano additives in composites and coatings for medical device applications. Medical Device and Manufacturing Minneapolis, Canon Communications, Minneapolis MN, October 2007.

Reitman MTF, Swanger LA. Practical tips on how to manage your technical expert in patent disputes. Ropes & Gray IP Master Class, Live Teleconference, June 2007.

Reitman MTF, Kennedy E. Root cause failure analysis and accident investigation. Lorman Educational Services, Live Teleconference, November 2007.

Reitman MTF. Plastics failure analysis: Case studies. Baltimore/ Washington Chapter of SAMPE, October 2006.

Reitman MTF. Plastics failure analysis. Baxter Global Plastics Processing Conference 2005, Schaumburg IL, 2005.

Fahey MT. Fiber mechanics, corrosion, sealants: Tales of a 3M materials scientist. Class of 1960's Scholars Program, Williams College, 1999.

Fahey MT. Adhesives and sealants for the telecommunications industry. Riverwood V Conference, St. Paul MN, 1998.

Advisory Appointments

UL Forum on Initiatives to Improve the Long Term Aging Program, LTTA Tools Working Groups, Underwriters Laboratories

Teel Manufacturing Technical Advisory Board

Solvay Advanced Materials Health Care Advisory Board

Peer Reviewer

Reviewer, Medical Plastics Technical Program Committee, Society of Plastics Engineers

Reviewer, Failure Analysis and Prevention Technical Program Committee, Society of Plastics Engineers

Reviewer, various book proposals and submissions related to polymer science, ASM International, Elsevier, John Wiley, Hanser, NIST

Appendix B

**Previous 4 years of Testimony,
Maureen T.F. Reitman, Sc.D., P.E.**

Testimony List of Maureen Reitman, Sc.D., P.E. (Last Four Years)

Eve Sherrer v. Truman Medical Center, Inc., et al. and **C.R. Bard, Inc.** (Circuit Court of Jackson County, Missouri at Kansas City) November 2015 (Deposition), January 2016 (Trial)

Elizabeth Way and Stuart M. Way v. George T. Besong, M.D., et al. (Circuit Court of the Seventh Judicial Circuit in and for Volusia County, Florida) December 2015 (Deposition) (Retained on behalf of **C.R. Bard, Inc.**)

Dennis Saunders v. **MTD, LLC**, et al. (United States District Court District of Connecticut) December 2015 (Deposition)

In Re: Kugel Mesh Hernia Patch Products Litigation (United States District Court District of Rhode Island) December 2015 (Deposition in Bowersock Matter); April 2016 (Deposition in Olmo Matter). (Retained on behalf of **Davol, Inc. and C.R. Bard, Inc.**)

Raymond and Elia Uribes v 3M Company f/k/a Minnesota Mining and Manufacturing, et al. (Superior Court of the State of California for the County of Santa Clara) January 2016 (Deposition) (Retained on behalf of **BASF Catalysts, LLC**)

BioDelivery Sciences International, Inc. (Petitioner) v. Monosol RX, LLC (Patent Owner) (United States Patent and Trademark Office, Before the Patent Trial and Appeal Board) January 2016 (Deposition)

Rene Douglas and Natalia Douglas v. **Martin Collins Surfaces & Footings, LLC**, et al. (Circuit Court of Cook County, Illinois) February 2016 (Deposition)

Roslyn Dauber, et al. v. **Monsanto Company**, et al. (Superior Court of the State of California for the County of Los Angeles) March 2016 (Trial)

Paul Brownlee, Fred Steele and Arutyun Karabadzakyan v. **Monsanto Company**, et al. (Superior Court of the State of California for the County of Los Angeles) April 2016 (Trial)

Lifetime Products, Inc. v **Russell Brands, LLC d/b/a Spalding, a Delaware Limited Liability Company** (United States District Court for the District of Utah, Northern Division) April 2016 (Deposition), May 2016 (Deposition)

Benito Walker et al. v **Monsanto Company et al.** (Circuit Court of the City of St. Louis State of Missouri) May 2016 (Trial)

The Irvine Company LLC v. Douglas Ross Construction, Inc., et al. (Superior Court of the State of California in and for the County of Santa Clara) June 2016 (Deposition) (Retained on behalf of **Milgard Manufacturing, Inc.**)

Darryl S. Dugas and Marsha Dugas v. 3M Company, et al. (United States District Court Middle District of Florida Jacksonville Division) July 2016 (Trial) (Retained on behalf of **Henkel Corporation**)

Zylon Corp. and Alan Zamore v **Medtronic, Inc.**, Medtronic Vascular, Inc., and Medtronic Vascular Holdings, Ltd., f/k/a Ave Galway, Ltd. (Supreme Court of the State of New York) July 2016 (Deposition), January 2017 (Trial)

The Estate of James Wurster, by Judith Wurster, its administrator, and Judith Wurster, individually v. **The Plastics Group, Inc.**, et al. (United States District Court Southern District of Iowa Central Division) August 2016 (Deposition), April 2017 (Trial)

Theresa O'Neill v. **Davol, Inc. and C.R. Bard, Inc.** (United States District Court District of Nebraska) September 2016 (Deposition)

Town of Westport and Westport Community Schools v. **Monsanto Company**, et al. (United States District Court District of Massachusetts) September 2016 (Deposition)

CDC San Francisco LLC v **Viracon, Inc.** et al. (Superior Court of the State of California for the County of San Francisco) November 2016 (Deposition)

Taylor Ferguson and Elyse Stanton v **Wal-Mart Stores, Inc., Wal-Mart Stores East, LP, and Wal-Mart Stores Arkansas, LLC** (Circuit Court of Sebastian County, Arkansas Civil Division) May 2017 (Deposition)

Naturalock Solutions, LLC v **Baxter Healthcare Corporation, a Delaware corporation, Baxter International, Inc., and Baxter Healthcare S.A.** (United States District Court for the Northern District of Illinois) May 2017 (Deposition)

In Re: **C.R. Bard, Inc.** Pelvic Mesh/Bard Litigation (Superior Court of New Jersey Law Division – Bergen County; Case No. 292; McGinnis, Rios) June 2017 (Deposition)

United States International Trade Commission: In the Matter of Certain Basketball Backboard Components and Products Containing the Same. (Retained on behalf of **Russell Brands, LLC.**) June 2017 (Deposition)

Velma Searcy v 3M Company, et al. (Los Angeles Superior Court). September 2017 (Deposition) October 2017 (Trial) (Retained on behalf of **Henkel Corporation and Dexter Hysol Aerospace LLC**)

Ansell Healthcare Products LLC v Reckitt Benckiser LLC (United States District Court for the District of Delaware) September 2017 (Deposition)

Kerry P. Becker v. C.R. Bard, Inc and Davol, Inc. In Re: **C. R. Bard, Inc.** Composix Kugel Mesh Hernia Patch Products Litigation (Superior Court, State of Rhode Island) October 2017 (Deposition)

Metalcraft of Mayville, Inc. v Flambeau, Inc. (Circuit Court of Dodge County, State of Wisconsin) October, November 2017 (Deposition)

DSM Dyneema, LLC v Thames Thagard, Ph.D., **Honeywell Specialty Materials, LLC, Honeywell Advanced Composites, Inc., and Honeywell International Inc.** (Superior Court Division, State of North Carolina) November 2017 (Deposition)

William Stemmler, et al. v **MTD Products, Inc.** et al. (Supreme Court of the State of New York Case No. 700029/2007) February 2018 (Trial)

Flowcrete North America, Inc. v Verdia, Inc., Anthony Crowell, David Keller, Ann Delve, and Sheryl Kunning. (District Court of Montgomery County, TX, 410th Judicial Court) March 2018 (Deposition)

A. Schulman, Inc. et al. v **Citadel Plastics Holdings, LLC et al.** v Robert J. Brinkmann. (Court of Chancery of the State of Delaware) April 2018 (Deposition) (Retained on behalf of **HGGC and Charlesbank.**)

Sonoma Pharmaceuticals, Inc. v Collidion, Inc. et al. (United States District Court Northern District of California San Francisco Division) April 2018 (Deposition)

Chemtall Incorporated v **BASF SE and BASF Corp.** (United States District Court Southern District of Georgia Savannah Division) July 2018 (Deposition)

City of Wyoming, MN et al. v Proctor & Gamble Company et al. (United States District Court for the District of Minnesota) September 2018 (Deposition) (Retained on behalf of **Rockline Industries, Inc.**)

Louisiana-Pacific Corporation and Louisiana-Pacific Canada, Ltd. V Akzo Nobel Coatings, Inc., Akzo Nobel Coatings, Ltd. Et al. (In the General Court of Justice Superior Court Division, Wilkes County, North Carolina) September 2018 (Deposition Part I and Part II) October 2019 (Deposition)

United States International Trade Commission. *In the Matter of Certain Blow-Molded Bag-In Container Devices, Associated Components, and End Products Containing or Using Same.* (Retained on behalf of **Heineken N.V., Heineken International B.V., and Heineken USA**) December 2018 (Deposition)

Dream Finders Homes, LLC and DFH Mandarin LLC v **Weyerhaeuser NR Company.** (District Court, County of Denver, State of Colorado) July 2019 (Deposition) September 2019 (Trial)

San Diego Unified Port District and City of San Diego v **Monsanto Company, Solutia Inc. and Pharmacia Corporation.** (United States District Court, Southern District of California) July 2019 (Deposition)

Petrolina Gonzalez v **Nutribullet LLC.** (Superior Court of the State of California for the County of Los Angeles-Central District) August 2019 (Deposition)

Integrated Laminate Systems, Inc. v **Wilsonart, LLC et al.** (Superior Court of New Jersey Law Division Camden County) August 2019 (Deposition) October 3, 2019 (Deposition) October 28, 2019 (Deposition)

Coordinated Proceedings Special Title (Rule 3.550(b)). Essure Product Cases: All Cases.
(Superior Court of the State of California, County of Alameda) Judicial Council Coordination
Proceeding No. 4887. November 2019 (Deposition). (Retained on behalf of **Bayer Corporation,
Bayer Healthcare, LLC, Bayer Essure, Inc. (formerly known as Conceptus Inc.), and Bayer
HealthCare Pharmaceuticals.**)

Exponent charges \$710 per hour for Dr. Reitman's consulting services in 2019. No part of
Exponent's compensation is contingent on the outcome of this matter.

Appendix C

Materials Considered

List of Information Considered

Literature

- Anezaki and Nakano, Journal of Hazardous Materials, 287, (2015), Figure 1 on pg 115.
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Depositions

- I have generally reviewed relevant experts depositions from previous Monsanto cases, including the Hartford, Westport, Lexington, and San Diego Matters. In particular, I reference within this report:
 - Deposition of Mike Coster, September 17, 2019 and exhibits
 - Deposition of Kevin Coughlin, Dated October 30, 2019 and exhibits
 - Deposition of Marcia Davis, dated September 10 and 11, 2019 and exhibits
 - Deposition of Marlene Feist, dated September 16 and 17, 2019 and exhibits
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Appendix D

Select Monsanto Customers Technical Sophistication

Company	Research Activities**	Year	Research Staff Count*
Acme Quality Paints (see Acme White Lead and Color Works, Sherwin Williams)	Paints, varnishes, lacquers	1946	Research Staff: 2; 8 chemists; technical personnel 21; additional personnel 4
		1956	Research Staff: 2; 14 chemists; other technical personnel 20; additional personnel 4
		1960	Research Staff: 2; 21 chemists; engineers: 2 chemical, 1 industrial, 1 mechanical; 18 technicians, 12 auxiliaries.
Adhesive Products, Inc. (or Adhesive Products Corporation)	Adhesives	1956	Research Staff: 2 director or managers; 4 chemists, 1 engineer; 2 other technical personnel
		1960	Research Staff: 1 director; 6 chemists, 3 technicians
Allied Chemicals (General Chemical Division, National Aniline Division, Solvay Process Division)	Coating compositions	1960	Research Staff: 1 technical director; 1 manager; 71 chemists; 64 chemical engineers; 5 entomologists; 1 metallurgist; 40 technicians; 61 auxiliaries
		1960	Research Staff: 1 VP research and engineering; 164 chemists; 32 chemical engineers; 158 technicians; 30 auxiliaries
	Plastics and Pigments	1960	Research Staff: 1 director of development; 1 director of research; 52 chemists; 14 chemical engineers; 48 technicians; 21 auxiliaries
Amercoat Corp	Coatings	1956	Research Staff: 2; 9 chemists; 1 engineer; 8 additional personnel
		1960	Research Staff: 1; 10 chemists; 1 chemical engineer; 9 auxiliaries
American Cyanamid	Coatings	1946	Research Staff: 10; 240 chemists; 58 physicists; 27 biologists; 16 metallurgists; 65 engineers; 2 physicians; 1 librarian; 431 additional
Ames Rubber Corp.	Rubber	1956	Research Staff: 1 VP Technical Director, 1 Chief Chemist and Technical Personnel Director, 3 chemists, 3 engineers, other technical personnel 5; additional personnel 3
		1960	Research Staff: 2 VP Technical Director, 1 Chief Chemist and Technical Personnel Director, 3 chemists, 3 engineers, 5 technicians, 3 auxiliaries

Company	Research Activities**	Year	Research Staff Count*
Armstrong Paint and Varnish	Paints	1956	Research Staff: 1; 7 chemists; 5 engineers; 10 technical personnel; 4 additional personnel
Baker Castor Oil Co	Paints	1946	Research Staff: 7 chemists 1 physicist; 1 engineer; 16 technical personnel; 11 additional personnel
		1956	Research Staff: 10 chemists, 1 engineer, 5 chemical engineers, 1 physicist; 6 other technical personnel; 13 additional personnel
		1960	Research Staff: 10 chemists; 3 chemical engineers, 8 technicians; 10 auxiliaries
Borden Chem Co	Paint and adhesives	1960	Research Staff: 1; 87 chemists; 14 chemical engineers; 7 wood technologists; 72 lab assistants; 40 auxiliaries
Celanese Chem Corp	Plastics	1960	Research Staff: 1-Vice President; 1 Technical Director; 1 Business Manager; 53 chemists; 18 chemical engineers; 1 civil engineer; 1 instrument engineer; 1 mechanical engineer; 1 mathematician; 2 physicists; 86 auxiliaries
Chemical Product Co	Coatings and Plastics	1956	Research Staff: 1 VP of research; 5 chemists
		1960	Research Staff: 1 chief chemist and technical personnel director; 1 biologist, 8 chemists, 1 chemical engineer, 10 technicians, 2 auxiliaries
Chrysler Corporation	Rubber and Plastic (Research Laboratory)	1956	Research Staff: Engineering Division research, design, and development execs: 23; R&D Design section: 10; 124 chemists, 806 engineers, 7 mathematicians, 42 metallurgists, 12 physicists, 3 psychologists; other technical personnel 1,483; additional personnel 1,683
Cook Paint and Varnish	Formulation and testing of protective coatings. (Research initiated 1913.)	1946	Research Staff: 17 chemists; 11 technical personnel; 1 additional personnel
	Paints, varnishes, lacquers, resins	1956	Research Staff: 44 chemists; 9 other technical personnel, 3 additional personnel
		1960	Research Staff: 1 VP (research), 1 Director of Research, 2 managers, 44 chemists, 9 technicians, 3 auxiliaries

Company	Research Activities**	Year	Research Staff Count*
Dennis Chemical Co	Vinyl dispersions, coatings, adhesives	1956	Research Staff: 8 chemists, 1 engineer
		1960	Research Staff: 1 aeronautical engineer, 9 chemists
Devoe & Raynolds	Paint, varnish, lacquer, coatings	1946	Research Staff: Laboratory Personnel: 107
		1956	Research Staff: 25 chemists, 11 other technical personnel, 10 additional personnel
		1960	Research Staff: 23 chemists, 1 mathematician, 1 chemical engineer, 1 civil engineer, 22 technicians, 6 auxiliaries (Long Range Polymer Research Facility included)
Dow Chemical Co.	Metallurgy (magnesium); inorganic chemistry; organic chemistry; physics. (Research initiated 1897.)	1946	650 chemists, chemical engineers, physicists, biologists, mechanical engineers, metallurgists, and 500 additional personnel carry on the research work for the Dow Chemical Company and its subsidiaries and divisions
	Plastics, agricultural chemicals, metallurgy (magnesium and titanium), inorganic and organic chemicals, pharmaceuticals, physics.	1956	Approximately 700 professionally trained persons; additional personnel, approximately 800.
		1960	2,000 scientists, technicians, and auxiliaries.
E.I. Du pont de Nemours & Company (Fabrics and Finishes Department)	Synthetic resins, varnishes. enamels, paints, undercoats, lacquers, plasticizers, and adhesives.	1946	Research Staff: Philadelphia, Pa. 60 chemists; technical personnel 55; additional personnel 29. Parlin, NJ: 40 chemists, 24 laboratorians; technical personnel 14; additional personnel 6. Flint, Mich.: 11 chemists, 10 laboratorians; additional personnel 5
		1956	Research Staff: Marshall Laboratory: 90 chemists, 7 engineers, 5 physicists; additional personnel 168
		1960	Research Staff: Marshall Lab: 66 chemists; engineers: 7 chemical, 1 mechanical; 2 physicists, 150 auxiliaries.
El Paso Natural Gas Company	Protective Coatings	1960	Research Staff: 4 chemists, 1 economist; engineers: 5 chemical, 3 electrical, 3 mechanical, 2 metallurgical, 1 mining; 1 other professional, 20 auxiliaries
Findley F. G. Company	Industrial adhesives	1956	Research Staff: 1; 4 chemists, additional personnel 3
		1960	Research Staff: 1; 4 chemists, 6 technicians, 3 auxiliaries

Company	Research Activities**	Year	Research Staff Count*
Glidden Co	Multiple Divisions Combined (Chemical, Paint, Metal, Pigments, Food, Coatings)	1956	27 Directors, 11 biologists, 172 chemists, 38 engineer, 3 metallurgists, 97 other technical personnel, 55 additional personnel, 3 others
		1960	23 Laboratory Directors, 2 bacteriologists, 2 biochemists, 171 chemists, 29 engineers, 32 other professionals, 125 auxiliaries (include Paint Division and Organic Chemical Division)
Goodrich	Plastics and Rubber	1956	5 biologists, 85 chemists, 22 engineers, 15 physicists, 9 others, 152 additional personnel. Industrial Products Division: 1 Technical Director, 1 Director of New Product Development, 4 Technical Superintendents, 69 chemists, 51 engineers, 16 others, 60 additional personnel
Goodyear Tire	Rubber	1956	5 biologists, 154 chemists, 144 engineers, 143 chemical engineers, 6 mathematicians, 1 metallurgist, 7 physicists, 34 others, 141 other technical personnel, 300 additional personnel
		1960	5 Development Managers, 4 biologists, 226 chemists, 5 agricultural engineers, 166 chemical engineers, 25 civil engineers, 12 electrical engineers, 17 industrial engineers, 124 mechanical engineers 7 textile engineers, 10 mathematicians, 1 metallurgist, 11 physicists, 164 technicians, 413 auxiliaries
Fuller, H. B.	Adhesives, Resins, Coatings	1960	Research Staff: 1 Vice President, Research and Development; 13 chemists; 2 chemical engineers; 6 technicians; 3 auxiliaries
Hercules Power Company (Hercules Experiment Station, Synthetics Laboratory)	Coatings Plastics, Food products	1946	Research staff: 3, 206 chemists and chemical engineers, 3 physicists; 408 additional personnel
		1946	Research staff: 8 chemists and chemical engineers
		1960	Research staff: (Harbor Beach, Michigan) Chemical Superintendent; 10 chemists and chemical engineers, 12 auxiliaries

Company	Research Activities**	Year	Research Staff Count*
Interchemical Corporation	Coatings, Varnishes, Resins, Adhesives	1960	Research Staff: 499
Johns-Manville Corp	Textiles, Plastics, Adhesives	1960	Research Staff: 613
Koppers	Dyestuffs, Chemicals, Adhesives	1960	Research Staff: Chemicals and Dyestuffs Div.; 1 named; 3 chemists; 4 chemical engineers; 4 technicians; 1 auxiliary
Minnesota Mining and Manufacturing (3M)	Adhesives	1946	Research Staff: 91 Chemists; 5 physicists; 53 engineers; 1 geologist; 54 technical personnel; 158 additional personnel
Socony-Vacuum Oil Company; or Socony Mobil Laboratories, Divisions, Socony Mobil Oil Company; or Socony Mobil Oil Co.	Petroleum	1946	162 chemists, 5 physicists, 151 engineers, 1 metallurgist, 37 technical personnel, 608 additional personnel.
		1956	235 Chemists, 230 engineers, 52 physicists, 2 biologists, 417 other technical personnel, 394 additional personnel.
		1960	4 biologists, 242 chemists, 53 physicists, 1 aeronautical engineer, 187 chemical engineers, 2 civil engineers, 19 electrical engineers, 5 general engineers, 3 industrial engineers, 52 mechanical engineers, 11 petroleum engineers, 1 power engineer, 10 mathematicians, 1 metallurgist, 5 scientists, 927 auxiliaries, 14 geologists
Morningstar-Paisley	Adhesives	1960	Research Staff: 2; 50 chemists, 30 auxiliaries
Nashua Gummed and Coated Paper Company; or Nashua Corporation	Adhesive compositions; protective coatings; paper and other laminations	1946	Research Staff: 1; 7 chemists, 5 engineers; technical personnel 7 ; additional personnel :2
		1956	Research Staff: 3; 9 chemists, 1 engineer; other technical personnel 6; additional personnel 1
		1960	Research Staff: 1; 16 chemists ; engineers: 1 chemical, 15 mechanical; 11 technicians, 2 auxiliaries.

Company	Research Activities**	Year	Research Staff Count*
National Lead Company	Paint vehicles, paint technology	1946	46 chemists, 5 physicists, 2 biologists & bacteriologists, 6 metallurgists, 4 engineers, 2 electrochemists; 32 additional personnel
		1956	135 chemists, 89 engineers, 25 ceramic engineers, 10 geologists, 12 mathematicians, 35 metallurgists, 10 physicists, 5 geophysicists; 125 other technical personnel; 95 additional personnel
		1960	4 biologists, 17 ceramists, 284 chemists; engineers: 96 chemical, 1 civil, 4 electrical, 2 electrochemical, 4 industrial, 18 mechanical, 2 petroleum; 1 geologist, 7 mathematicians, 27 metallurgists, 4 mineralogists, 17 physicists, 223 technicians, 262 auxiliaries.
National Starch Products, Inc.; or National Starch & Chemical Company	Adhesives, sizes and coatings, resin emulsion paint bases	1956	Research Staff: Executive VP & Technical Director; Assistant VP, Research; Director of Personnel Relations. 61 chemists, 5 engineers; 49 additional personnel.
		1960	Research Staff: VP, Research; Director of Personnel; 70 chemists, 15 chemical engineers, 35 technicians, 45 auxiliaries
Phillips Petroleum Company	Petroleum, Rubber, Plastics, Chemicals	1946	Total: 428. 9 named 129 chemists 10 physicists 2 biologists 81 engineers 18 tech. personnel 179 additional
		1956	Total: 1,045 12 named 8 biologists 186 chemists 224 engineers 12 math 34 physicists 12 tech. personnel 557 additional
		1960	Total: 875 7 named 5 biologists 170 chemists 146 chem. Eng. 18 electrical Eng. 34 mech. Eng. 9 other engineers 2 geologists 8 math 20 physicists 11 misc. 445 auxiliaries
Polymer Industries	Adhesives	1960	Research Staff: 21

Company	Research Activities**	Year	Research Staff Count*
Pittsburgh Plate Glass (PPG)	Paints, pigments, resins, synthetic enamel	1946	Research Staff: (Paint Division) 2 named; 122 scientific professions; 93 lab assistants; 26 additional personnel
		1956	Research Staff: (Thresher Paint and Varnish Division) 1 named, 5 chemists, 7 tech. personnel, 2 additional
		1960	Research Staff: Paint Research and Dev. Center: 2 named; 80 chemists; 8 chem. Eng.; 68 technicians; 27 aux.; Barreled Sunlight Paint Co.: 1 named; 6 chemists; 2 aux.
Products Research Co	Adhesives, Coatings, Sealants, and Adhesives	1960	Research Staff: 24
Raybestos-Manhattan	Adhesives	1960	Research Staff: (Manhattan Rubber Division) engineers: 13 chemical, 4 mechanical; technicians: 12 rubber, 14 others; 5 auxiliaries.; (Raybestos Division) 12 chemists, engineers: 9 chemical, 2 electrical, 8 mechanical; 1 physicist, 42 technicians, 2 auxiliaries
Reynolds Metals (Development Laboratory, Light Metals Division)	Coating formulation, adhesives	1946	Research Staff: 9 chemists, 1 biologist, 4 engineers; technical personnel 7; additional personnel 10
	Coating, adhesives	1956	Research Staff: 14 chemists, 7 engineers; additional personnel 33
Ruberoid Co (Funkhouser Mills Division)	Paints, coatings	1960	Research Staff: 5 chemists, 1 other professional, 9 auxiliaries
Sherwin-Williams	Paints, varnishes, lacquers	1946	Research Staff: 435
		1956	Research Staff: 341
		1960	Research Staff: 529

Company	Research Activities**	Year	Research Staff Count*
Solvay Process (See Allied Chemical Corp)	Plastics, Petrochemical, Textiles, Pigments, Chemicals (Semet-Solvay Division, and Semet-Solvay Petrochemical Division, Solvay Process Division)	1960	27 chemists, 36 technicians, 2 chemical engineers
Sun Chemical Corp	Paint; varnishes; industrial finishes and coatings	1946	Research Staff: 57 chemists; technical personnel 37; additional personnel 25
		1956	Research Staff: 50 chemists; other technical personnel 140
		1960	Research Staff: 52 chemists, 10 chemical engineers, 3 psychologists, 170 technicians, 100 auxiliaries

Company	Research Activities**	Year	Research Staff Count*
Swift & Co	Food Products, Plastics, Containers	1946	1 59 technically trained chemists, physicists, biologists, chemical engineers, bacteriologists, microscopists, histologists, nutritionists, dietitians, home economists, veterinarian, scientific professions, lab assistants, etc.; additional personnel 80
		1956	16 bacteriologists, 26 biologists, 96 chemists, 5 chemical engineers, 2 doctors of veterinary medicine, 27 engineers, 3 food technologists, 12 home economists, 4 mechanical engineers, 3 mathematicians, 1 physicist; 21 others, 45 other technical personnel; 57 additional personnel
		1960	10 animal husbandmen, 16 bacteriologists, 37 biologists, 77 chemists, 2 dairy technologists; engineers: 42 chemical, 5 electrical, 18 mechanical, 1 mining; 3 food technologists, 10 home economists, 1 physicist, 2 poultry husbandmen, 3 veterinarians, 50 technicians, 48 auxiliaries
Union Carbide Chemicals Co (Technical Service Laboratory)	Coatings	1960	Research Staff: 120. 1 biologist; 50 chemists; engineers: 20 chemical, 2 mechanical; 2 physicists, 45 auxiliaries
W.R. Grace	Pertroleum, Packaging, Adhesives, Chemicals	1960	2 Directors of Research, 1 Director of Research Services, 125 chemists, 102 technicians, 72 auxiliaries

*Research Staff Counts may not be exhaustive to all employees at a company

**Relevant research activities are grouped by general purpose